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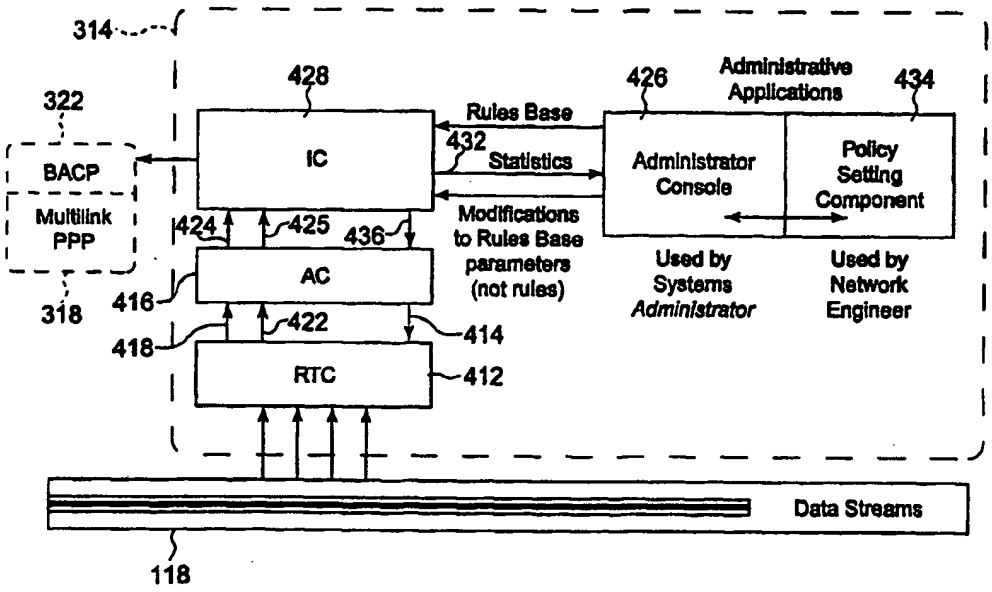

(57) Abstract

Allocation of telecommunication systems bandwidth is provided preferably in a predictive fashion. Packets are identified with particular data streams and characteristics of the data streams are used to predict probable future bandwidth requirements. Such predictions are used to allocate high–bandwidth channels, such as ISDN B channels and to close or switch channels as in accordance with predicted needs. Preferably the system is self–learning and can modify a rules base for making allocation decisions e.g. based on actual use statistics.

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PREDICTIVE BANDWIDTH ALLOCATION METHOD AND APPARATUS

FIELD OF THE INVENTION

The present invention permits prioritizing packets or other communications and/or allocation of bandwidth, such as allocation of ISDN-bearer channels to be based on a prediction of the size or other characteristics of a data stream, preferably with consideration of the effect of allocation on telecommunication costs.

BACKGROUND OF THE INVENTION

In the early days of telecommunications, users had few service options available, under what has now become known as POTS (plain old telephone service), often being restricted to choosing the number of incoming lines, private or "party line" service and, for larger users, selection of a private branch exchange (PBX). In contrast, modern users can select among a variety of services, each having associated advantages, disadvantages and costs, including (in addition to POTS) ISDN (Integrated Services Digital Network) service, T1 service, cellular service and the like. Services such as ISDN and T1 which provide a potential for large-bandwidth telecommunications have become particularly important as telecommunications use has expanded beyond voice traffic to include telefacsimile (fax), digital (or audio-modulated digital) signals (used, e.g., for network or Internet communications), and the like. Communication of some types of information, such as video information, digital file transfers, still images, streaming audio and the like, create heavy (if often short-lived) bandwidth demands.

Nevertheless, high-bandwidth services such as ISDN have not widely supplanted older, less-suitable telecommunications options, primarily because of the costs associated with high-bandwidth services (which may include not only installation fees, but connection fees and tariffs). Part of the cost associated with ISDN and other high-bandwidth options arises from the fact that, in many such systems, a

large-bandwidth channel is allocated to each subscriber who must therefore bear the cost of the entire bandwidth for extended periods even though the user may only be able to benefit from, or use, the large bandwidth intermittently and for relatively short periods (e.g. during times when relatively large files are being transferred). Accordingly, systems have been proposed which bear a rough (and imperfect) analogy to a "party line" in which a given bandwidth is allocated for use by multiple users, but at different times, as their needs dictate.

One proposed system is referred to as (AO/DI) (Always On/Dynamic ISDN). In an AO/DI system, the "D" channel is continuously available (Always On). The relatively low bandwidth D channel serves as the "home" channel for a user and one or more B channels are utilized for relatively large transmissions and are closed as they are no longer needed. Such a system permits costs to be shared among a plurality of users, and cost to an individual user is reduced in a number of fashions. A given user need not bear the cost of a large-bandwidth channel during times it is not being used or is not needed by that end-user. Because ISDN lines are shared, a reduced number of lines is necessary to supply a given group of users, leading to reduced line charges and usage of equipment.

Certain protocols have been proposed in connection with an AO/DI system, including a multi-link point-to-point protocol (MLPPP) which allows aggregation of multiple channels, and a bandwidth allocation control protocol (BACP) which runs "on top" of MLPPP and provides a vendor-independent standard for initiation and management of opening and closing channels. Descriptions of the proposed AO/DI, MLPPP and BACP can found, e.g., at "Always On/Dynamic ISDN," RFC-1990 and RFC 2125 respectively, available from the Vendors' ISDN Association (VIA) (a non-profit California corporation located at Bishop Ranch 2, 2694 Bishop Drive, Suite 105, San Ramon, CA 94583) or on the Internet at http://ftp.via-isdn.org/, and incorporated herein by reference. These three systems, however, while they provide the capability of switching or allocating bandwidth, do not dictate a system for determining or deciding when to make such allocations or deallocations, much less suggesting a decision-making system which would be effective and efficient.

One possible approach is a queue-depth system which allocates a large-bandwidth channel when the number of communication packets that have accumulated in a processing queue has reached a predetermined threshold. Such a system, in essence, is based on a consideration of past traffic volume only. If traffic which has already occurred has reached a predetermined volume in a given period of time, a wider-bandwidth channel is allocated. Although such a system will function at a certain level, it will not necessarily achieve the goals of lowering costs and providing for ease of use. Indeed, there are situations in which a queue-depth system would increase costs over those that would be incurred if

no bandwidth switching or allocation took place. For example, if a threshold is reached just before the end of, e.g., a file transfer, a queue-depth system will nevertheless allocate additional bandwidth (and, typically, cause costs to be incurred for the end user) even though the end user will receive little or no benefit from the additional bandwidth, (since the file transfer will be complete before or shortly after such additional bandwidth is allocated). Because such thresholds would be predetermined and fixed, these problems cannot be solved by merely selecting a different threshold value. For example, although raising the threshold might have avoided unnecessary charges from a futile B channel allocation in the example above, transfers with other characteristics (e.g., frequent large but short data transfers) would receive no benefit from the system with a high threshold.

A queue-depth system, thus requires, for efficient use, that the threshold should be established so as to accommodate the particular mix of traffic for a given end-user. However, a typical end-user will have neither the skills nor the time to achieve an optimal or even useful threshold value. Thus, the queue-depth system, in addition to being unable to achieve cost savings goals in many situations, also imposes relatively heavy administrative costs in implementing the system. Furthermore, a queue-depth system is inflexible and cannot adjust to changes in the characteristics of the data traffic, (e.g. as traffic changes throughout the day or for a longer period of time.) For effectiveness, any adjustments to the threshold in a queue-depth system would require a significant expenditure of time by a relatively highly-skilled administrator. Additionally, a queue-depth system can not allocate bandwidth early in a given data stream (e.g. can not allocate bandwidth after only the first few -- such as 1 to 4 -- packets) but must wait at least until enough packets have arrived to reach the predetermined queue threshold.

Accordingly, it would be useful to provide a system which can achieve bandwidth allocation so as to fulfill the goal of lowering costs for high bandwidth telecommunications without imposing burdensome time and skill requirements to set up and maintain such a system. It would also be advantageous to provide a system which can accommodate to time-varying traffic or usage patterns. It would further be useful to provide a system that is capable of deciding on bandwidth allocation early in a data stream, such as after only the first few packets have been received.

Some systems for providing wide-bandwidth access place substantial burdens on end users such as requiring end users to invest in significant additional hardware or software. Accordingly, it would be useful to provide a system which achieves cost effective and efficient provision of wide bandwidth capability for telecommunications without requiring significant installation of additional

equipment or software at the end user location (client side) in order for such a system to operate.

Additionally, some systems impose significant burdens on telecommunications companies in order to implement efficient bandwidth allocation. For example, implementing a system which modifies or "resides" in a protocol stack would require a vendor to recertify the protocol stack, adding to the vendor's costs to implement such a system. Because telecommunications systems use equipment and software from a wide variety of vendors, bandwidth allocation procedures which depend on a certain level of interaction with vendor equipment or software could, in some situations require different versions to interoperate, depending on which vendor supplies the basic routing or other telecommunications equipment and software (i.e., will be vendor-dependent) imposing costs which involve selecting the proper version required for interoperability and the development and implementation costs associated with providing multiple different versions of a bandwidth allocation system to operate in connection with multiple router vendor devices and software.

Accordingly, it would be useful to provide bandwidth allocation apparatus and procedures which reduce or minimize costs to telecommunications companies and developers, such as systems which reduce or avoid recertification costs and which are at least partially vendor-independent.

SUMMARY OF THE INVENTION

The present invention includes a recognition of at least some of the problems of previous procedures and apparatus, including as described above. The present invention involves making bandwidth allocation procedures decisions based at least partially on a predictive scheme, i.e. using characteristics other than (or in addition to) queue-depth to increase the likelihood that, on average, bandwidth allocations will achieve more efficient bandwidth utilization and, preferably, lower costs to users (at least on average). In this and other disclosed fashions, the present invention can be used to provide and manage a level of service for data and signal communications.

According to one embodiment, data packets are identified as belonging to particular data streams. A characteristic of the data stream (e.g. its classification related to a type of data being transferred, such as GIF data, streaming video data, text E-mail or batch binary downloads) enters into a decision regarding whether it is likely to be efficient and/or cost-effective to allocate additional

bandwidth for use in transmitting future packets in this stream. For example, in one embodiment, receipt of the first few packets of a GIF stream may result in allocating additional bandwidth (if, e.g., the system predicts that a relatively large amount of GIF data will be forthcoming during the remainder of the data stream) whereas receipt of the same amount of data classified as text E-mail (i.e. which has achieved the same queue-depth as the above-described GIF stream) may not be allocated additional bandwidth if the system predicts that the text stream will be relatively short-lived or unnoticed, e.g. if not received immediately.

In one embodiment, the system can access various components or fields of data packets to associate a packet with a particular stream (such as source/destination/port information, or, in some cases, data field information). Preferably the system can use various procedures for classifying a particular data stream as to the type of data. In some implementations, in addition to (or in place of) using classifications of data streams as to type of data, other information useful in predicting future bandwidth requirements for a data stream are employed (such as knowledge, for a given user, that a particular type of data stream occurring during a certain time period is likely to be relatively long or relatively short). The present system is preferably a heuristics-based system and, in one embodiment, such additional predictive information is developed and used by a self-learning or artificial intelligence system. In this way, the system may accommodate itself to changes over time in a fashion that is automatic. In this context, "automatic" means that the goals are achieved by a computer or computer system without a requirement for analysis, decisions or other inputs from human operators or administrators (although, if desired, the system can be configured to permit human input to supplement or override the automatic analysis). Providing at least certain portions of the invention as byte code systems is believed to assist in more easily modifying rules (as described below), e.g. to more easily achieve self-modification or self-learning.

Preferably the system is substantially modularized. In one embodiment, the module which directly monitors or is coupled to the telecommunications line is configured so that it contains only, or substantially only, those items which must be performed in real-time and is preferably configured to operate rapidly, such as by operating as a byte code system, preferably an efficient or optimized byte code system. Other components of the system, such as those configured to analyze system operation (e.g. after-the-fact) and/or provide learning or other artificial intelligence capabilities, (and which typically do not operate in real-time) preferably are configured to reduce or minimize the load on routing computers, such as by operating substantially in a cycle-stealing mode (to employ routing computer facilities only during times when the routing computer would otherwise be idle)

In one embodiment, the system is substantially vendor-independent preferably by employing vendor APIs. Vendor-independence is preferably assisted by code modularization and by restricting vendor-dependent components, e.g. to several well-defined functions.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of a telecommunications system useful in connection with an AODI networking application;

Fig. 2 is a timing diagram depicting an example of channel use allocated by queue depth;

Fig. 3 is a block diagram depicting the flow of information useful for bandwidth allocation according to an embodiment of the present invention;

Fig. 4 is a block diagram depicting a modular implementation of an embodiment of the present invention;

Fig. 5 is a block diagram similar to the diagram of Fig. 4 but depicting additional client side components;

Figs. 6A and 6B are a block diagram and a flow chart, respectively, illustrating procedures using the components of Fig. 4;

Figs. 7A and 7B are a block diagram and a flow chart, respectively, illustrating procedures in connection with a real time component according to an embodiment of the present invention;

Figs. 8A and 8B are a block diagram and a flow chart, respectively, depicting procedures in connection with an implementation component according to an embodiment of the present invention;

Figs. 9A and 9B are a block diagram and a flow chart, respectively, depicting procedures in connection with an adaptation component according to an embodiment of the present invention;

Fig. 10 illustrates a display of network router information in connection with an embodiment of the present invention;

Fig. 11 illustrates a display of router statistics usable in connection with an embodiment of the present invention;

Fig. 12 depicts a display of policy options usable in connection with an embodiment of the present invention;

Fig. 13 depicts a display of a policy editor usable in connection an embodiment of the present invention;

Figs 14A and 14B are a block diagram and a flow chart, respectively, of an embodiment of the present invention illustrating self-learning;

Figs. 15 is a flow chart of an example, according to an embodiment of the present invention, involving increasing bandwidth following classification of a data stream;

Fig. 16 is a flow chart of an example, according to an embodiment of the present invention, involving increasing bandwidth when a data stream is not identified; and

Fig. 17 is a flow chart of an example, according to an embodiment of the present invention, involving increasing bandwidth in response to data volume.

Fig 18A is a schematic block diagram of counter used in a pegboard self-learning system.

Fig. 19 is a schematic diagram of a table for tracking unknown-type data streams usable in accordance with an embodiment of the present invention.

Fig. 20 is a schematic block diagram illustrating opening according to one embodiment of the present invention.

Fig. 21 is a schematic block diagram illustrating packet rate control according to an embodiment of the present invention.

Fig. 22 is a schematic block diagram illustrating security features according to an embodiment of the presentation.

Fig. 23 is a schematic block diagram illustrating media routing according to an embodiment of the present invention.

Fig. 24 is a schematic block diagram illustrating out-of-stream process according to embodiments of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Before describing features of the present invention, it is believed useful to describe certain features of an AODI networking application and an example of a queue-depth control. In the following, references to types of lines or communications links includes, with reference to the OSI model, any "layer one" physical medium. As will be apparent to those of skill in the art after understanding the present disclosure, some or all features of the invention can be implemented when the telecommunications line or communications link is a wireless link. In the system depicted in Fig. 1, a data server 112 (which may include one or many computers) and client 114 are coupled, to a router 116, with one side of the router 116, in the illustrated configuration, being coupled to the server side using an ISDN communications link 118. In a typical situation, the router 116 is coupled to a client that may involve a high bandwidth connection 133 to a Local Area Network (LAN) 135. The illustrated ISDN link includes a D channel 122 and first and second B (bearer) channels 124, 126. The D channel 122 has a relatively narrow bandwidth e.g. for accommodating data rates of up to about 9.6 kilobytes per second (KBPS). Each B channel 124, 126 has a relatively wide bandwidth, capable of accommodating 64 KBPS (for a total of 128 KBPS when both B channels are in use). As noted above, in an AODI system, the B channels are circuit-switched (e.g. according to BACP and MLPPP protocols).

In one implementation of AO/DI, the D channel 122 is always on (always off-hook). In one implementation of AO/DI, calls are initially placed and handled over the D channel, using packetized procedures such as those known as X.25 (which is described, e.g., in RFC-0874). Because the D channel is always-on, it is possible to provide always-available service, including, e.g., "push-mail".

When it is determined that additional bandwidth should be provided, one or both of the bearer channels are switched to assist in transferring the data. Typically the bearer channels will use MLPPP (e.g. without the X.25 packetization used on the D channel). When it is determined that such additional bandwidth should be discontinued, one or both of the B channels should be disconnected.

The usefulness of AO/DI will be related to the manner in which bandwidth is allocated, i.e. the manner in which decisions to add or drop B channels are made. It is possible to base decisions on recent volume of data traffic, such as by basing the decision on whether the depth of data in a router queue 128 has reached a predetermined threshold. Fig. 2 presents a (simplified) example of queue-depth decision-making, and also illustrates one of the shortcomings of such a system. In Fig. 2, the queue depth 212 is initially low but begins rising relatively rapidly when data communication commences at time T1. As noted above, the communication will initially be carried by the D channel 214. However, because the D channel is relatively low-bandwidth, the queue-depth rapidly rises after T1, reaching a pre-defined queue-depth threshold 216 at time T2. The event of reaching the threshold 216 at time T2 triggers a decision to switch-in B channel number 1. Implementation of this decision takes a certain amount of time and thus, in the illustration of Fig. 2, the B channel number 1 is switched-in at time T3 218. Because the bandwidth of the B channel is relatively large, the queue depth rapidly falls 222 to a level below the threshold 216. In the example of Fig. 2, the data being transferred has a relatively large bandwidth requirement and, after a time T3, the queue depth continues to rise, although more slowly than during the period following time T1. In the illustrated example, the queue depth once again reaches the threshold 216 at time T4 224 triggering a decision to add the second B channel. In the illustrated example, however, it happens that the data transfer is complete shortly after the time T4. Nevertheless, because of the delay involved in switching in a B channel and, subsequently, the delay involved in discontinuing or switching out a B channel, B channel number 2, in the illustrated example, is switched in at time T5 and is not switched out until time T6. Thus, in the example of Fig. 2, the user will be charged for use of B channel number 2 between time T5 and T6, even though the user received no benefit from use of B channel number 2 (since data transfer was completed before the B channel was switched in).

Fig. 3 depicts, in block form, a system which, according to the present invention, can base bandwidth allocation decisions on information other than (or in addition to) queue depth. Details of the system will be described below. In general, as shown in Fig. 3, information related to characteristics of the data is passed 312 to a decision system 314. The decision system determines whether and when bandwidth should be allocated or deallocated and these decisions are executed 316 using MLPPP 318 and BACP 322 to implement such switching in a manner

to avoid disrupting data flow while achieving the desired bandwidth allocation. In the embodiment detailed below, the decision system 314 uses a rules base for making decisions and, preferably, provides a development environment for building the rules base. In one embodiment, the decision system 314 provides self-learning capability (artificial intelligence) e.g. so that it can modify its own rules base to meet changing environmental demands. The rules base architecture is preferably vendor-independent and preferably contains a management tool which is identical across various vendors' hardware systems, e.g. permitting administrators to manage varied systems from a single console at the same time.

In one embodiment, heuristic analysis is used to achieve a self-learning system. One example of a heuristic analysis is a so-called "pegboard" system. In one example of a pegboard-type heuristic method, a system is provided which (a) determines when to perform an evaluation of the performance of the system; (b) how performance is to be evaluated; and (c) how to revise the rules when performance is deemed sufficiently poor. In one pegboard system, separate counts of the total number of messages (such as the total number of messages of a particular type) and of the number of such messages or data streams that are handled correctly, are accumulated in a software (or in some cases a hardware) counter. The counters of total data stream of a particular type and of a total number which are handled "correctly" can be visualized as first and second pegboards 1812, 1814 as illustrated in Fig. 18A in which darkened circles in the first pegboard 1812 represent the number of data streams of a particular type (in the illustration, the number of e-mail sessions) in a particular period (e.g. since the last evaluation of performance) and darkened circles in the second pegboard 1814 depict the number of e-mail sessions which were handled correctly. For purposes of illustration, it may be supposed that the currently-operating rules base is configured on the basis of an assumption that e-mail sessions are relatively small and thus provides for rules which do not increase the bandwidth for e-mail sessions. Thus, in the illustration of Fig. 18A, each time a new e-mail data stream is handled, the counter or pegboard 1812 is incremented. The handling of the e-mail session is evaluated to determine whether the e-mail session was handled correctly and, if correct handling is determined, the second counter or pegboard 1814 is incremented. The evaluation procedures can be configured in a number of ways for determining whether handling of a e-mail session was correct. For example, since the rule that specifies not increasing bandwidth for e-mail sessions is based on an assumption that an e-mail session is small, it is possible to configure the evaluation software such that handling of a particular e-mail session under the current rules base is considered "correct" if, in fact, the particular e-mail session is small (less than a threshold amount). Other types of evaluation of performance are also possible. For example, it would be possible to configure software such that the actual handling of the e-mail was compared to one or more possible alternative ways of handling the e-mail (such as increasing bandwidth) and to determine whether the actual handling could have been improved (in a sense of , e.g., providing better performance at

relatively low cost, or providing closer compliance to user-established performance criteria) had an alternative handling procedure been used.

In any case, it can be seen from the above how the software may be configured to automatically maintain a count in pegboards 1812, 1814. As will be clear to those of skill in the art, it is also possible to provide a set of counters or pegboards for other types of messages (e.g. in addition to the illustrated e-mail pegboards).

In order to perform function (b), at some point the information effectively accumulated in the pegboards is considered ripe for evaluation. A number of systems can be used for determining when evaluations are to take place. In the illustration of Fig. 18A, evaluation is performed whenever either of the counters or pegboards 1812, 1814 has reached a maximum value, i.e. when either of the pegboards 1812, 1814 is "full" 1816. Other criteria for initiating the evaluation can also be used such as passage of a predetermined period of time, reaching a threshold in the first (but not second) pegboard, reaching a threshold in the second (but not first) pegboard, a perceived change in performance of the system as a whole, the cost of the system as a whole, a user-initiated request to evaluate performance, reaching thresholds which are variable (such as thresholds which vary by time of day) and the like.

Because, in the illustrated embodiment, the "correct" handling of each individual e-mail session was individually and preferably continuously evaluated, once the evaluation period has been reached, performing the system evaluation can be achieved merely by comparing the number of correctly-handled sessions (1814) to the total number of sessions (1812) in a given timeframe. For example, it is possible to configure the software such that if the ratio of correctly handled e-mail sessions to total number of e-mail sessions in the timeframe is less than a predetermined ratio, the system will initiate a change to the rules base in an attempt to improve performance. In the illustrated example, since the current rules base involves not increasing the bandwidth for e-mail sessions, in response to detection of unacceptably poor performance (a relatively low ratio of correctly-handled e-mail sessions to total e-mail sessions) the system will modify the rules base to, e.g., allow for an increase in bandwidth in response to e-mail traffic, such as a predetermined minimum of e-mail traffic. As will be clear to those of skill in the art, other ways of modifying the rules base upon detecting poor performance can also be provided such as initiating queuing of the e-mail messages or the like.

Although Fig. 18A illustrates a pegboard-type heuristic method, other types of self-learning, preferably heuristic self-learning methods can also be used. For example, a more general heuristics method may involve obtaining information on a plurality of different characteristics of data streams (such as date, time, effective data rate, port number and handling under current rules base) which

may then be analyzed to determine, over a number of data streams, which factors appear most pertinent to the performance of the system. As one example, the system may be configured to obtain and store information relative to those data streams or messages which are of an unknown type. As noted above, this system typically will have some procedure in the current rules base for handling unknown-type data streams, resulting either in a decision to switch to a higher bandwidth or not to switch to a higher bandwidth for these data streams. In one example of a more general heuristics method, the system may, for example, keep track of the port number for such unknown-type data streams and store (e.g. in a table 1912 such as that illustrated in Fig. 19) the frequency of unknown data types associated with each port and whether switching occurred. According to this example, periodically (or at user initiated or otherwise selected times) an analysis is performed to evaluate handling of unknown data streams under the current rules base. For example, the information illustrated in Fig. 19 can be used to select those sessions or session types which appear to have the largest impact on the system (e.g. the most packets). In this illustration, the category of unknown data streams having the largest impact (such as unknown data streams with a particular port address which occurred most frequently) are then analyzed to determine whether they were handled "correctly". Analysis of "correct" handling can be performed by a number of methods, including those as described above in connection with the example of Fig. 18. For example, it may be determined whether different switching decisions would have resulted in acceptable performance but at a lower cost (e.g. if the system has been configured, or users have indicated a desire, to keep costs at the minimum level consistent with a desired level of performance). In one example, if it is determined that a relatively large number (e.g. exceeding a threshold) of unknown-type data streams was not handled correctly, a decision is automatically made regarding how to modify the rules base in order to attempt to improve performance.

In one embodiment, this decision regarding how to revise the rules base is based on a further analysis which correlates the correct and incorrect switching decisions to a number of different possible correlates (such as predetermined potential correlates that had been determined as likely candidates). Examples include attempting to correlate correct and incorrect switching decisions to date and/or time the packets were sent, the "bursty/continuous" behavior of packets, the effective data rate over a given transmission period and the like.

On the basis of this analysis, one or more of the correlates are identified as having a relatively significant correlation to the correctness of handling and such correlation is used as a basis for modifying the rules base. For example, if it is determined that most of the incorrectly handled unknown-type data streams occurred between the hours of noon and 3 p.m., and/or for a particular port number the rules base would be modified to make different (e.g. opposite)

switching decisions for unknown data streams which occur during those hours. The system will then temporarily add new rules for this unknown data type and will use this new rule set to replace the previous rule set for the unknown session types. The counters (such as those depicted in Fig. 19) are then reset, at least for the categories relevant to the changed rules, and the system continues to operate and accumulate information for later heuristics-based performance analysis.

In addition using identification of data stream type for purposes of bandwidth switching, data type can be used for other purposes. In one example, data stream types are identified and used for queuing of data streams (such as weighted fair queuing). Such queuing can be used in place of or in addition to the above-described band selection or switching. In the illustration of Fig. 20, the system 2012 is placed in the data stream such as being placed in a router 2014 which in the illustrated embodiment, receives an inbound 10 Mbps LAN packet stream 2016 and outputs a 128 Kbps WAN packet stream 2018. In the illustrated embodiment, voice and video data packets are provided with the highest priority 2022 while e-mail and Internet "web" packets are provided lesser priority 2024, 2026. If the bandwidth of the output stream 2018 is not fully utilized, packets of packet stream 2016 are placed onto the output line 2018 substantially without buffering. However, if the bandwidth of the output stream 2018 is being fully utilized, the system queues packets as they arrive e.g. by placing the packets in different queues 2028a,b,c. The different queues are provided with different priorities, such as by providing the queue 2028a corresponding to voice and video with the highest priority 2022. The router 2014 outputs packets from the queues 2028a,b,c but does not necessarily output the packets in a manner which reflects the order in which they arrived or necessarily providing equal distribution from the various queues. Instead, packets in the queue 2028a with the highest priority are output with a greater frequency (compound the input frequency or equal or proportional frequency) than packets in lower-priority queues 2028b,c. Thus, whereas the incoming packet stream 2016, voice and video represent approximately one-third of the packets, the voice and video packets are output more frequently so that in the output stream 2018 illustrated in the example of Fig. 20, they represent 50 percent of the output packets.

Fig. 21 presents another fashion in which a system 2112 in a data stream (such as in a router 2114) can be used to enhance performance and/or reduce cost. The example illustrated in Fig. 21 relates to a situation in which a video receiver sends, e.g. over a 10 Mbps LAN packet stream 2116 to a video sender (e.g. over 128 Kbps WAN packet stream 2118) requests (such as in the form of an acknowledged "ACK" message) for video packet data of a particular size. In this example, the system 2112 is used for packet rate control. For example, it may be that the video receiver requests a particular amount of video data but that it would not be most efficient to transmit all of the packets necessary to fulfill the data request at once. According to the example of Fig. 12, after determining the

effective incoming and outgoing data rates of packet streams 2116, 2118, the system takes into consideration a "virtual" data rate for video, such as a data rate that has been previously requested by an administrator. For example, the administrator might request video data at a rate of 64 Kbps or, e.g. 8 Kbps. The system 2112 calculates the maximum "chunk" size of data in order to maintain rate control. For video (for packet rate control over a link such as 2118 which is 128 Kbps), this might be set, e.g., at 4 KB chunks requested two times per second This chunk size may be adjusted as needed to prevent time-outs. In this situation, when a request "ACK" for video packet data is received, the system 2112 resizes the amount of data requested. For example, the system may select a size which is the minimum value that falls between the maximum chunk size calculated above and the data requested. As one example, if the video receiver sends a request for 32 KB, the system 2112 instead, outputs a request, to the sender, for 4 KB. When the system 2112 notes that the requested 4 KB has been sent from the sender 2126, thus leaving a remaining amount of 28 KB 2128, the system 2112 then outputs another request for 4 KB. This procedure is then repeated until the requested 32 KB have been provided to the receiver. In this way, the system 2112, in response to receiving a particular request 2122, converts this into a series of different requests 2124, 2132, etc. in order to provide control of the packet rate in a fashion which is consistent with the overall desired and economical performance of data transfer.

Fig. 22 provides an illustration of another manner in which data stream type information may be used, e.g. to provide security, such as "firewall", functions. In the illustration of Fig. 22, the system 2212 is positioned in the data stream (such as in a router 2214). The illustration of Fig. 22 provides an example in which the desired security features include rejecting all file transfer protocol (FTP) packets 2216 from within a satellite bank unless the time is between 4 p.m. and 8 p.m. and a secure software key has been sent to the router.

In the illustration of Fig. 22, FTP packets 2216 on the 10 Mbps LAN packet stream are not provided on the 128 Kbps WAN packet stream because, in the illustration, either the time is not between 4 p.m. and 8 p.m. or the secure software key has not been sent to the router. In one embodiment, the system can be configured, e.g., to allow access to the satellite banks systems by HQ systems only if HQ systems first "unlock" a secure connection to the router allowing, e.g., up to a 15-minute transmission window.

Fig. 23 illustrates an example of a use of a system 2312 in a router 2314 for routing different types of data streams on different communications media. For example, in the illustrated embodiment, packets on a LAN packet stream 2316 may be routed over a low-speed, low-cost dial-up WAN 2318, over a mid-speed, mid-cost ISDN WAN 2322, or a high-speed, high-cost fiber-optic WAN 2324.

Other types of possible media will occur to those of skill in the art. In the illustrated embodiment, the LAN packet stream can include a number of different types of packets including voice and video packets 2326 which are, in this example, considered to be timing-critical data, requiring maximum performance, e-mail packets 2328, considered in this example, to be not time-critical and requiring treatment so as to minimize cost, and web packets 2332, considered in this example, to be of average importance. The system 2312 can operate to route packets, depending on the packet type, to the various media 2318, 2322, 2324, e.g. via buffers 2334a,b,c associated with each medium. In the example of Fig. 23, the rules base for the system 2312 is configured such that, when timing-sensitive or mission-critical packets are received, e.g. 2326, these are sent through the highest-speed link or WAN 2324 available. When less time-critical packets are received, such as web packets 2332, and packets for interactive applications, these are sent through a less expensive medium-speed link or WAN 2322, and when e-mail packets and other time-insensitive packets are received, these are sent through the lowest cost link or WAN 2318.

Although illustrations of the use of a system have been provided including illustrations involving switching, it is possible to provide a number of applications of a system outside of switching. Many such applications involve providing to a system 2412, copies of packets in the data stream 2416 and/or inserting generated packets 2418 into the packet stream, as illustrated in Fig. 24. Examples of applications of a system outside of switching include monitoring the line e.g. for over-utilization; tracking traffic types and reporting to the administrator; tracking usage characteristics of users who connect remotely; comparing efficiency and cost of a current connection to a theoretical connection type (e.g. given a profile of the theoretical connection type); acting as an enhanced intelligent firewall (to analyze security and recommend improvements); simulating and/or replaying data for diagnostic purposes; improving transmission efficiency of data sent through the system (e.g. to diminish traffic latency); investigating unforseen ways to improve efficiency; communicating with other systems to automatically provide redundancy; and/or tracking byte patterns within packets e.g. to identify and prevent viruses, identifying and acting upon tunneled protocols, secure protocols and the like.

The decision system 314 includes a number of components which, in one embodiment, are distributed. Some components reside on vendor's equipment while others reside on system developers' and/or administrators' work stations.

The system preferably operates on a stream-based rather than packet-based level. As is known to those of skill in the art, X.25, multi-link protocol and similar systems transfer a given data stream by transferring a plurality of data packets, each of which contains a portion of the data stream. The present system, rather

than attempting to make separate decisions for each data packet, identifies the data streams which the packets make-up and makes decisions based on information regarding each different data stream. The decision system 314 can determine any or all of the size, start time, end time of a data stream e.g. through an ISDN interface. Preferably, the system can make this determination after obtaining information from only the first few packets of a data stream, and in some cases after obtaining information from only one (such as the first) packet of a stream (which may contain sufficient header or other information to identify the data type of the stream).

In addition, the decision system 314 can identify other characteristics of a stream. In an ISP (Internet Service Provider) environment, for example, the decision system 314 can determine if a particular stream represents an FTP (File Transfer Protocol) session, an HTTP (Hypertext Transfer Protocol) request to a server, or some other type of transmission. This information about stream-type can be used in making decisions about predicted needs on the underlying ISDN lines and thus serve as a basis for deciding, e.g., when to add channels and/or when to close channels. Table I provides for purposes of illustration, a list of selected data stream types and certain characteristics of the data streams which, in a given environment, may be useful in predicting future bandwidth needs for that data stream. Other data types and characteristics are well known to those of skill in the art, including, for example, HTTP (hypertext transfer protocol), SMTP, SNMP and H.323.

Table I

Data Stream Type	Typical Characteristics
FTP	Large size, large standard deviation in size, typically not time critical.
HTTP	Requests are small average size; Responses are large average size and large standard deviation in size, relatively time critical.
SMTP (E-mail)	Small average size, not time critical.
Video Conference/ Audio streams	Large average size, time critical.

In one embodiment, predictions regarding future bandwidth needs for a data stream are implemented by a rules base. The rules base preferably can be modified, either automatically or manually, e.g. based on traffic statistics. Preferably, the decision system 314 automatically collects statistics useable for modifying the rules base. Although it is possible to implement a decisions system

314 according to the present invention in a number of fashions, implementation by a rules base configuration is believed to allow system developers to more readily program the decision system 314 to deal with different data streams and, preferably, in a relatively intuitive fashion such as via a series of yes/no decisions (with certain decisions providing the conditions for other decisions). Preferably such system design or programming is independent of the underlying hardware and thus can be used with any of the variety of hardware configurations. In one embodiment, reprogramming or modifications of the rules can be accomplished without interrupting operation of the system, e.g. without the need to re-boot the router 116.

Preferably, to assist in achieving efficient execution of the decision system 314, at least portions of the decision system 314 are executed as byte code. Preferably, the rules base system is compiled into vendor-independent byte code before being downloaded to vendor equipment. Preferably the byte code is specifically developed for operating on packets and for making binary (yes/no) decisions. Additional efficiency is preferably implemented by automatically ordering the binary decisions for optimum or increased efficiency. In one implementation, some or all binary decisions, as they are made, result in setting up flags for that session, so that decisions, once made, do not have to be repeated unless necessary.

Preferably, the byte code can be provided without the need for compiling (such as when an interpreter, rather than a compiler, provides the byte code). This approach can be useful in providing new or modified byte code which can be loaded on the real time component without the need to interrupt or re-boot the system or components thereof.

Efficiency of execution is further promoted by the componentized or modularized structure of the decision system 314, such as the embodiment depicted in Fig. 4. In the embodiment of Fig. 4, a real time component RTC 412 interfaces to the ISDN 119 data streams (preferably to a router vendors' protocol stack) to obtain information regarding packets as they pass through the router 116. Preferably the RTC 412 does not reside in such stack but, instead, obtains information regarding packets through vendor application programming interfaces (API's). Since the protocol stack itself is not modified, there is no need to recertify a protocol stack when the present system is implemented, provided the vendor provides the necessary API's.

Preferably, the RTC 412 includes substantially all of the real time operations of the decision system 314. In the depicted embodiment, the RTC 412 performs a number of functions. It is capable of identifying start, middle and end packets of particular data streams. The RTC 412 makes decisions on when to switch

channels, open channels and close channels using rules provided in a byte-code system or engine. The RTC 412 further collects statistics about data traffic. The type of statistics which are collected are determined, preferably, by the byte code engine.

In the embodiment of Fig. 4, the byte code engine which is executed by the RTC is provided to the RTC 414 by an adaptation component (AC) 416. This architecture permits modifying or updating the byte code engine executed by RTC. In particular, the AC 416 receives statistics on data stream characteristics as well as the channel switch/open/close decisions made by RTC 422. By comparing the received statistics against the existing rules base which the RTC is currently using, the AC 416 can determine if the rules base might be better adapted to the current environment. Preferably the AC 416 can automatically (without human intervention) generate a revised or modified version of a byte code engine and download the improved or adapted engine 414 to the RTC 412. In this way, the AC 416 modifies or adapts the RTC to meet specific needs of a changing environment. The statistics used by the AC are also preferably passed on to an administrator console 424 (in the depicted embodiment, via an Implementation Component (IC) 428.

Preferably the AC 416 need not operate in real time (or put another way, a slowdown or stoppage of the AC 416 will not have an immediate effect on current data flow). Modularizing or compartmentalizing those components, such as AC 416, which need not run in real time provides the opportunity to avoid placing excessive computational loads on the router computer since non-real time components such as the AC 416 can be configured to operate only as router processor cycles are available (i.e. to use the router processor during times when the router processor would otherwise be idle). Use of cycle-stealing permits relatively complex and time-consumptive analysis to be accomplished without affecting overall performance and without the need for significant (or, in many cases, for any) addition or upgrading of routing processors or other hardware. Cycle-stealing and other efficiency-enhancing measures as described herein make it feasible to employ the learning or artificial intelligence approaches described herein which, it is believed, were previously generally considered infeasible for telecommunications routers because of the computational load involved. The AC 416 also passes-on the switch/open/close channel decisions (made by the RTC) 425 to the IC 428. A major function of the IC 428 is to implement the decisions made by the RTC by interfacing to vendors' implementations of BACP 322 and MLPPP 318. Preferably the IC 428 makes calls to BACP using vendors API's in order to switch channels, open channels and tear down channels, as decided by RTC and conveyed through the AC 416. IC 428 also stores statistical information 424 and passes it on 432 to the administrator console 426. As depicted in Fig. 10, the Administrator Console 426 preferably may be configured to display, e.g. information about all routers in a network, such as status 1012, numbers of total,

active and inactive routers 1014 and the like. As depicted in Fig 11, the Administrator Console 426 preferably may be configured to display, e.g. detailed customizable views of many types of statistics for various routers, such as status 1112, Bytes and Packets in various time periods 1114a, 1114b and the like.

New or modified rules bases can be developed by administrators using depicted administrative applications 426, 434. Such new rules bases are downloaded 436 by the IC 428 (e.g. via Internet Protocol (IP) Sockets) to the AC 416 where they are converted into (preferably optimized) byte code that the RTC 412 can use. Conversion into byte code, particularly efficient or optimized byte code, can be a difficult task. In one embodiment, the task is achieved or assisted using prime implicants theory-based procedures.

Preferably the administrator console 426 provides a graphical user interface (GUI) to assist an administrator in setting or changing parameters for rules bases running on routers in a network (or specific portions of rules bases such as router policies or user policies). For example, in one embodiment, as depicted in Fig 12, the administrator console 426 can be configured to facilitate selection of certain policies, such as by displaying drop-down boxes or other selection items, e.g. for setting maximum bandwidth for privileged users 1212, setting policies for certain data types 1214, naming policies 1216 and the like. Preferably the administrator console 426 also provides an easily accessible and understandable view of the statistics 432. In the depicted embodiment a Policy Setting Component 434 is used, e.g. by a network engineer, to create and modify rules bases. As depicted in Fig 13, such policy setting is preferably facilitated by arranging in "tree" views 1312 of a type familiar to many programmers or network engineers

Preferably the administrator console permits simultaneous management of one or more decision systems 314 and multiple rules bases from a single location. Use of an interface such as a sockets-level IP interface to all decision systems assists in accomplishing this task. In such a configuration, the interface presented on the administrator console, as well as the language used for creating and modifying rules bases, is vendor-independent, and thus will appear the same to an administrator regardless of the type of vendor hardware present on a given IP network.

As illustrated in Fig. 4, it is possible to implement the present invention in the absence of modification to hardware or software of an end user or client 114. However, it is also possible, and in some cases advantageous, to provide a system which includes certain client-side applications e.g. as depicted in Fig. 5. In one embodiment, a client connection component 514 assists in setting up a users' ISDN connection to both a telephone company and the ISP (Internet Service

Provider). An administration component 516 can be provided to offer an end user a degree of control over his or her own ISDN usage (e.g. through use and modification of a user policy) which may then be integrated into the rules base running on the router to which the user is connecting. This may be used, e.g., to permit users to further increase efficiency and reduce costs of data transmission based on their special knowledge of their own requirements. A user may, for example, wish to indicate a particular balance between costs and level of service, or may wish to specify that, for example, e-mail messages are to receive top priority regardless of cost. The server side may also wish to have some potential for influence on operation of the system. In one embodiment, when an ISP wishes to change or add options available to an end user, the service provider can immediately "hot load" the modified options to the client side.

Figs. 6a and 6b depict components and process steps involved in making channel switching decisions according to one embodiment of the present invention. In the depicted configuration, when a data packet reaches a router 612,614, a copy of the packet 616 is delivered to the switching system 618 and, in particular, to the RTC 622 by the router 624. The RTC uses the rules base 626 to decipher the packet and determine whether or not to change the bandwidth 628. If the RTC does not change the bandwidth, the RTC will record this decision and do nothing further with regard to the packet 632. If the RTC determines that bandwidth should be changed, the RTC will record its decision and will send a command 634 to the IC 636 via the AC 638. The IC 636 uses a bandwidth control method to request adjustments to the bandwidth by the router 642, essentially opening or closing bandwidth switches 644a,b,c. Regardless of whether a particular packet results in a change in bandwidth, the RTC 622 will occasionally or periodically report on the decisions it has made to the AC 646. The AC 638 will evaluate these decisions and may use its own larger rule set to modify the rules base 626 of the RTC 648.

Figs. 7a and 7b illustrate operation of the RTC in greater detail. A packet processor 712 places a newly-arrived packet copy into a packet queue such as a first in, first out (FIFO) queue 714 so that it can be processed by the rules base engine 716. The rules base engine 718, when it receives a packet from the queue 714 resets any "per packet" instance variables 722 and starts processing 724 via the rules base 626. The rules base 626 deciphers the packet, e.g. relying on an opcode list and/or parser 726, records statistics related to the packet and its status, and determines if a change in bandwidth should be made 728. If execution of the rules base results in a change in bandwidth, the RTC 622 records its decision, and sends a command 734 to the IC 636 (via the AC). As noted above, the IC 636 uses a bandwidth control method to request adjustments 736 to the bandwidth by the routers 612. The RTC 622 as noted, periodically or occasionally reports its decisions 738 and statistics to the AC 742. Before processing the next packet, the RTC will determine if there is a new or modified

rules base received from the AC 638. If so, the RTC will wait (i.e. will not process new packets from the queue 714) until completion of processing (using the old rules base) of the current packet, will replace the old rules base with a new rules base 746 and continue processing 748.

Figs. 8a and 8b depict processing and components of an IC 636 according to an embodiment of the invention. In the depicted embodiment, a comm manager 812 can receive, e.g., status information from administrative applications 426, 512 with policies being saved via a data manager 814 (e.g. on a mass storage device 816) and may request information, to be satisfied with recent data from the data manager. The mass storage device 816 may be used for storing rules bases, data dictionaries, user parameters, statistics, and the like. The comm manager 812 notifies an internal command controller 822 about events 824 such as new policies. The command controller 822 may also receive new statistics and status updates from the AC 826 which it may save to the data manager 828. The command controller 822 also receives commands from the RTC 832 such as commands to change bandwidth which it passes on 834 to a connection manager 836, 838. The connection manager 836 coordinates requests to switch up and switch down, e.g. by communicating 842 with a router's 612 connection manager (e.g. a BACP or the like), and handles the progress of connection requests 844.

Figs. 9a and 9b illustrate operation and components of an AC according to an embodiment of the present invention. The IC 636 may pass a set of policies 912 (which may be in the form of a new rules base, a data dictionary, or other forms) preferably in a platform-neutral format (i.e. which can be read by any implementation of the system 618) 914. A loader 916 converts the policies into a platform-specific format, e.g., numbers are converted into 16-bit signed on Intel format, opcodes are stored in a more compressed format, and the like 918. The loader passes the policies to 922 ACBM 924. The ACBM 924 which may be provided, with a data dictionary 926a, a parser 926b, an opcode list 926c and the like, derives a rules base from the policy and passes it 928 to the prime implicant 932 of the analyzer 934. The prime implicant 932 uses rules of logic to reduce, reorganize and compress the rules base so that it is more efficient 936. The prime implicant 932 then passes the rules base 938 to the RTC 942. In addition to or in place of basing a rules base on information received from the IC, the ACBM 924 may use its own set of policies and statistics received 944 from the RTC to generate a new rules base and send it to the prime implicant 946.

Figs. 14a and 14b illustrate a manner of facilitating self-modification or self-learning according to an embodiment of the present invention. In the depicted embodiment, the IC downloads 1412 a data dictionary or rules base to the AC 1414. If the AC receives a data dictionary, it first extracts a rules base e.g. via the ACBM 924 before downloading to the RTC 622, 1416. The RTC 622 processes

and switches according to its rules base 626. Periodically or occasionally, the RTC passes statistics 944 and/or information (fingerprints) about unknown packets it has found, to the AC 638, 1418. The AC 638 uses algorithms built into its data dictionary 926a or rules base to modify, add, or delete rules 1422. Changes made to a data dictionary or rules base are passed up 1412 to the IC for storage 1424. The AC 638 extracts and passes 1426 a new, unoptimized version of the rules base to the prime implicant 932. The prime implicant 932 uses rules of logical reduction to optimize the new rules base before it passes an approved rules base to the RTC 1428.

Fig. 15 provides one example, of a relatively simple nature, of how a known packet may cause a switch up (or the addition of a channel). In the example of Fig. 15, the rules base 626 receives a packet and identifies the packet type of being of HTTP (hyper text transfer protocol) type 1512. The rules base determines that this packet is a header for a new connection 1514. The rules base then determines that the packet specifies a session length of 67OK bytes 1516. The rules base determines that this session length is greater than the maximum number of bytes needed to switch up 1518. The session (data stream) is logged (information stored, associated with a data stream identifier) and the progress of the data stream or session is tracked 1522. The RTC makes a note (e.g. by storing data, setting a flag, and the like) to report statistics regarding this data stream and/or packet to the AC, which will assist the AC in making a determination of whether the switch up was correct (resulted in the desired data transfer effect) and/or whether the rules base should be modified 1524. The RTC will then send a message, via the AC, to the IC to switch up (add bandwidth) 1526.

Fig. 16 provides a simple example of a situation in which receipt of a packet of unknown type may result in a switch up. In the example of Fig. 16, a packet is received whose data type cannot be identified 1612. The rules base will obtain information (fingerprint) regarding this packet such as data length, associated data streams, number of packets in a stream and the like, and, as before, will make a note to pass such fingerprint information on to the AC 1614. In the depicted embodiment, there are two conditions 1616, 1618, which may cause the rules base to request a switch up. The rules base may be configured to request a switch up when either of these conditions 1616, 1618 is fulfilled, or may require that both conditions 1616, 1618 be fulfilled before requesting a switch up. In the depicted embodiment, the first condition is that the new data rate, including the new packet, is greater than the maximum data rate for the current bandwidth setting 1616. The second condition is that the data rate has been too high (exceeding a threshold) for a longer period than a predetermined time for the current bandwidth setting 1618. Depending on the configuration of the rules base, when either or both of these conditions are fulfilled, the rules base will send a message to the IC (via the AC) to switch up 1622.

Fig. 17 illustrates an example of how an aggregation of streams may cause a switch up. In the example of Fig. 17, the rules base first identifies a packet as signifying the start of an e-mail session 1712. As before, the rules base logs and tracks this session or data stream and makes a note to report statistics to the AC 1714. The rules base determines that it should not request a switch up merely because of the data type, i.e. merely because this is an e-mail session 1716. In some configurations, the rules base may be configured such that e-mail sessions are considered non-time critical, and thus normally do not result in a switch up. In the depicted example, it is determined that the new data rate, including the new packet, is greater than the maximum for the current bandwidth setting 1718 and/or that the data rate has been too high for longer than a predetermined time for this current bandwidth setting 1722. As a result, even though the packet is identified as an e-mail packet, the rules base sends a message to the IC (via the AC) to switch up 1724. Bandwidth aggregation can be used both in the context of aggregation of predicate bandwidth and aggregation of actual bandwidth.

In light of the above description, a number of advantages of the present invention can be seen. The system preferably achieves more efficient use of available bandwidth thus permitting multiple users to share B channels or other high bandwidth media. In one embodiment, the present invention can provide a ratio of users to B channels greater than about 3:1, more preferably greater than about 5:1, even more preferably greater than about 8:1 and yet more preferably greater than about 10:1. Preferably the system makes bandwidth allocation decisions based on considerations such as by considering the effect an allocation will have on a user's telecommunications charges, e.g. taking into account the current rate in variable-rate environments. The present invention is capable of accommodating changes in data traffic and preferably is capable of automatically learning and adapting to changing conditions. The present invention can be configured to configure and/or modify a decision rules base taking into account current tariffs and other charges so as to provide high bandwidth service as needed or desired while reducing or minimizing costs to end users. The invention provides a vendor-independent mechanism for implementing and executing a bandwidth allocation decision. The same decision procedure can be run on different vendors' hardware interchangeably without modification. Such vendor independence further facilitates hardware upgrades since migration to new hardware can be achieved with little or no modification to the decision system of the present invention. In this way vendor investments in the described decision system are protected and new systems are compatible with procedures of previous systems. The present invention provides an intuitive GUI development environment and language for creating and modifying rules bases used by the system. The development environment allows vendors to fully and easily integrate any decision algorithm work that has already been done into the rules base. The rules bases themselves are preferably modular and reusable. The present invention permits rules bases to be hot loaded to the router and implemented during normal operation i.e. without taking down or re-booting

routers and without stopping the data streams. The present invention facilitates development and testing, as well as modifications of algorithms since the ability to achieve hot loads permits frequent downloads during testing. In one embodiment, a single administrator console can control a relatively large number of widely distributed routers simultaneously. Multiple administrator consoles can be used to manage the same group of locally and/or remotely connected routers (for example, different consoles could be used by administrators on different shifts, primary backup and tertiary consoles could be used for redundancy, or specific consoles can have responsibility for a separate portion of routers. The present invention provides advantages directly to end users by facilitating connection to the users' telephone company and ISP and providing the end user with a certain level of control over his or her own ISDN usage. Although client side applications may be used, client side installation is not required thus providing a desirable degree of flexibility, openness and future-proofing. The present system preferably is compatible with any vendor hardware on remotely connected machines which supports BACP and MLPPP, e.g., if sufficient memory and processing resources are available. The present invention provides a way to allocate bandwidth, such as ISDN bandwidth, without relying solely on queue depth, preferably using predictions of future bandwidth requirements based on data stream characteristics.

A number of variations and modifications of the system can also be used. It is possible to use some features of the invention without using others. For example, it is possible to implement a rules-based, data-stream oriented bandwidth allocation procedure without using automatic learning procedures. The present invention can involve combining data-stream oriented bandwidth allocation with other approaches, such as using queue-depth of "level-of-service" allocation methods when the system is unable to (or lacks the time or other resources to) identify the data type of a data stream. In some embodiments, it may be preferable to permit aggregation of two or more data streams for purposes of allocating bandwidth for such data streams (e.g. in cases where neither of two (or more) co-existing data streams by itself justifies additional bandwidth, but overall efficiency is promoted if the aggregated data streams are provided with additional bandwidth). The present invention can be used in an environment in which there are multiple network transport media or in which there is only one network transport medium, e.g. as in an Ethernet or ADSL network. In one embodiment, the invention can be implemented using queues and assigning virtual or software channels. Although the present invention has been described in the context of an ISDN implementation, the present invention can also be applied to other telecommunications systems or media including T1, Frame Relay, ATM, Ethernet, Fiber and xDSL (e.g. by providing and using virtual channels). The present invention can be used in connection with networks that combine fiber optics, frame relay, and Ethernet, and can be used in connection with networks that have only one type of medium (e.g. using virtual or software channels) Although it is believed that features such as modularization, real time

segregation, byte code, decision flagging and the like, contribute to efficient execution, it is possible to implement an operable system which does not include one or more of these items. Although certain features of the present invention were described in the context of ISP usages, the present invention can be implemented in a number of other contexts. For example, for remote network access, the system can reside on a remote access router (e.g. owned by a company which uses ISDN to connect outside users to that router). The system can precisely allocate bandwidth in e.g., a corporate environment for accommodating telecommuters (whose data transactions tend to be sporadic and patterned). The present invention can be used in connection with router-to-router connections. For example, point of sale systems in satellite stores connecting to a central site. The present invention may permit routers e.g. at satellite locations, to remain constantly connected to headquarters over switched connections without incurring incremental charges, even over long-haul lines. In such a system, low level throughput (such as price checks, credit card authorizations and the like) can take place over the always-on low-bandwidth D channels, with high level transactions such as price file transfers, coupon downloads, store transactions, summary uploads and the like utilizing additional bandwidth as needed on demand. The present invention can be used in a number of different ways, including any or all of setting priorities for data streams, queuing and/or holding data streams (or packets thereof), providing firewall or other security features, and providing a policy engine.

Although an embodiment of the present invention can be provided in the C language and/or using known artificial intelligence language principals such as those of Prolog, it is possible to implement the present invention using other programming languages and approaches.

Although the present invention has been described by way of preferred embodiments and certain variations and modifications, other variations and modifications can also be used, the invention being defined by the following claims.

What is claimed is:

1. A computer-implemented process, in a telecommunications system for switching at least some packets, making up a telecommunications stream, comprising:

identifying at least one packet, being transmitted on a medium having a first bandwidth, as a component of said stream;

identifying a first characteristic of said stream, using at least said packet, wherein said characteristic is at least partially predictive of likely data size of said stream;

identifying additional packets as components of said stream; and

deciding, based on at least said first characteristic, whether to switch at least some of said additional packets to a second medium having a bandwidth larger than said first bandwidth.

2. A process as claimed in claim 1 wherein said step of identifying said at least one packet is based on at least one of source, destination and port information included in said packet.

3. A process, as claimed in claim 1, wherein said step of identifying said at least one packet is based on information in a data portion of said packet.

4. A process as claimed in claim 1, 2 or 3 wherein said first characteristic is obtained from packet header information.

5. A process as claimed in any one of claims 1 to 4 wherein said first characteristic is a data type of said stream.

6. A process as claimed in claim 5 wherein said data type is selected from among

a file transfer protocol type;

a GIF type;

a streaming video type;

a streaming audio type;

a hypertext transfer protocol type;

an SMTP type;

an SNMP type; and

an H.323 type.

7. A process as claimed in any one of claims 1 to 4 wherein said first characteristic is a usage characteristic.

8. A process as claimed in claim 7 wherein said usage characteristic is associated with one or more time periods for a given destination.

9. A process as claimed in claim 7 wherein said usage characteristic is associated with status of communications links in said telecommunications system.

10. A process as claimed in claim 9 wherein said status includes current throughput.

11. A process as claimed in any one of claims 1 to 9, wherein said first medium is a D channel of an ISDN line and said second medium is a bearer channel of an ISDN line.

12. A process as claimed in any one of claims 1 to 9 wherein said telecommunications system includes a medium having at least a D channel and a bearer channel and said step of deciding comprises deciding whether to initiate or discontinue use of said bearer channel.

13. A process as claimed in claim 12 wherein said medium is used to provide an ISDN service or an AO/DI service.

14. A process as claimed in claim 12 wherein said medium is used to provide T1 service.

15. A process as claimed in claim 14 wherein said medium is used to provide service other than T1 service.

16. A computer-implemented process, in a telecommunications system for switching at least some data in a telecommunications stream, comprising:

identifying a first characteristic of said stream, wherein said characteristic is at least partially predictive of likely data size of said stream;

deciding, based on at least said first characteristic, whether to switch at least some additional data so as to provide different data transmission properties, wherein said deciding is performed using a first stored rules base;

automatically evaluating the effectiveness of said step of deciding.

17. A process, as claimed in claim 16, further comprising modifying said rules base, based on said step of evaluating.

18. A process, as claimed in claim 17, wherein said step of modifying said rules base is performed automatically, to provide a self-learning computer implemented telecommunications switching process.

19. A process, as claimed in any one of claims 16 to 18, wherein said step of deciding is implemented using a heuristic process.

20. A process, as claimed in any one of claims 16 to 19, wherein said step of evaluating comprises evaluating both cost and level of service.

21. A process, as claimed in any one of claim 16 to 19, wherein said step of evaluating comprises evaluating aggregate predicate bandwidth.

22. A process, as claimed in claim 16, wherein said step of evaluating comprises evaluating on the basis of user-identified criteria.

23. A method, as claimed in any one of claims 16 to 22, wherein said different data transmission properties are selected from the group consisting of different bandwidth properties and different effective data transmission speed properties.

24. A computer implemented process, in a telecommunications system, for queuing data streams, comprising:

identifying at least first and second different data types of first and second input data streams wherein said input data streams define a first

frequency of data packets of said first data stream with respect to the packets of the second data stream.

queuing at least said packets of said first and second data steams; and

outputting packets of at least one of said first and second data streams wherein said one of said data streams is output at a frequency, different from said first frequency

25. A computer implemented process in a telecommunication system for controlling packet rate comprising:

receiving at least a first request for data which includes a first data size indicator;

outputting, in response to said receipt, a plurality of data requests having second data size indicators different from said first data size indicator.

26. A process as claimed in Claim 25 further comprising:

calculating a calculated size of data required to maintain rate control and wherein said second data size is the lesser of said calculated data size and said first data size.

27. A computer implemented process, in a telecommunication system, for providing security, comprising:

identifying the data stream type of substantially all packets transmitted on said telecommunications system;

forwarding only those packets which meet predefined criteria, wherein said predefined criteria include criteria relating to the data stream type of a packet.

28. A process as claimed in Claim 27 further comprising forwarding packets for at least a first data stream type only if a predefined password has been received.

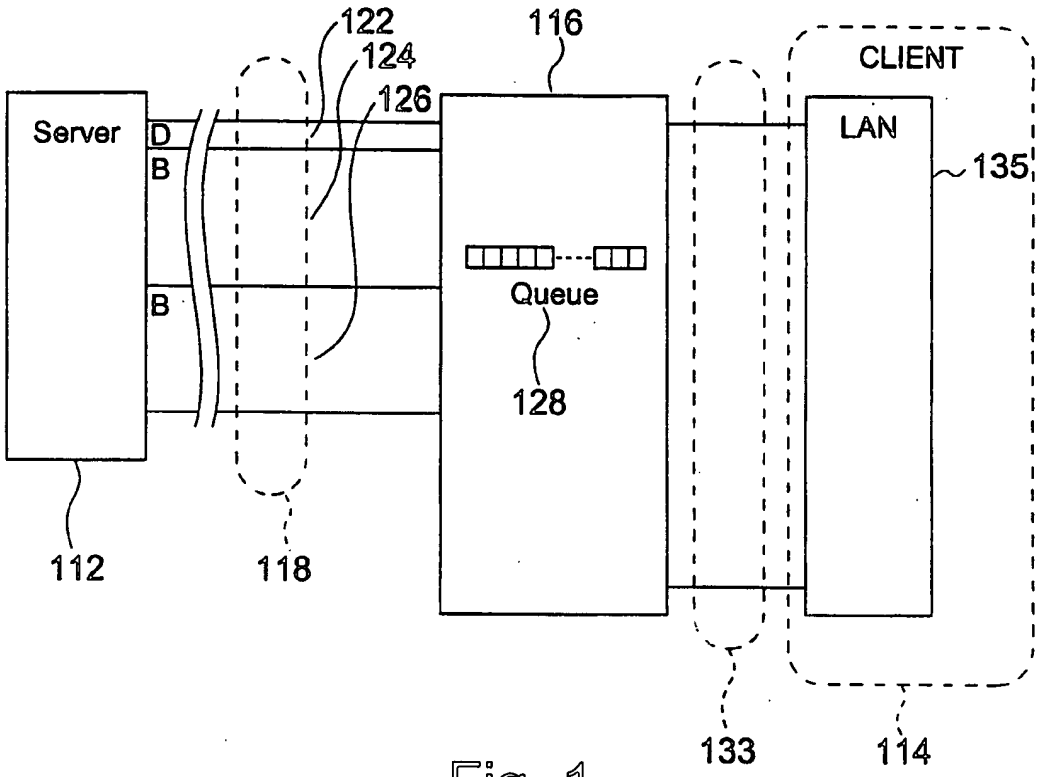

122
124
126
116
CLIENT
Server
D
B
B
LAN
135
Queue
128
112
118
133
114

Fig. 1

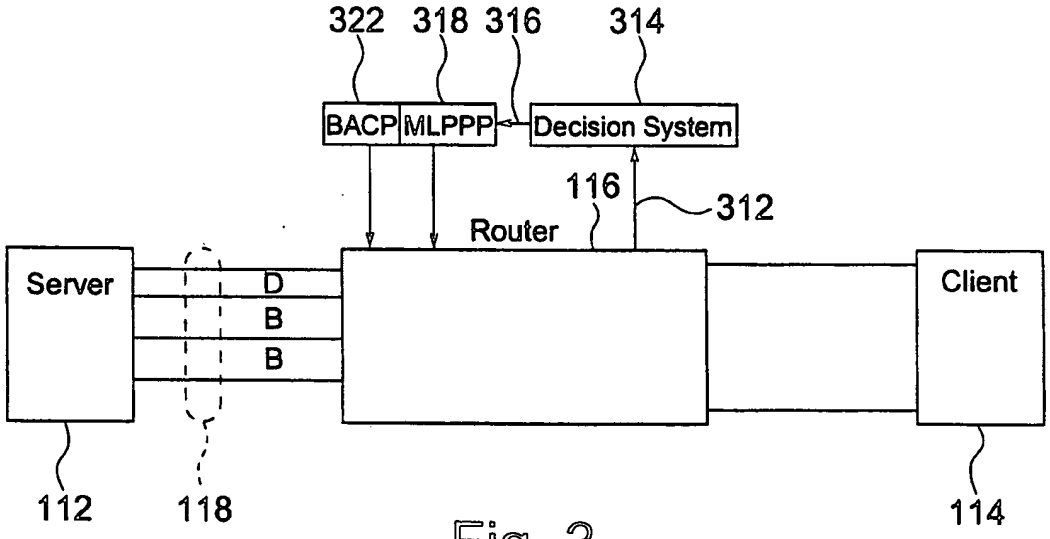

322
318
316
314
BACP
MLPPP
Decision System
116
312
Router
Server
D
B
B
Client
112
118
114

Fig. 3

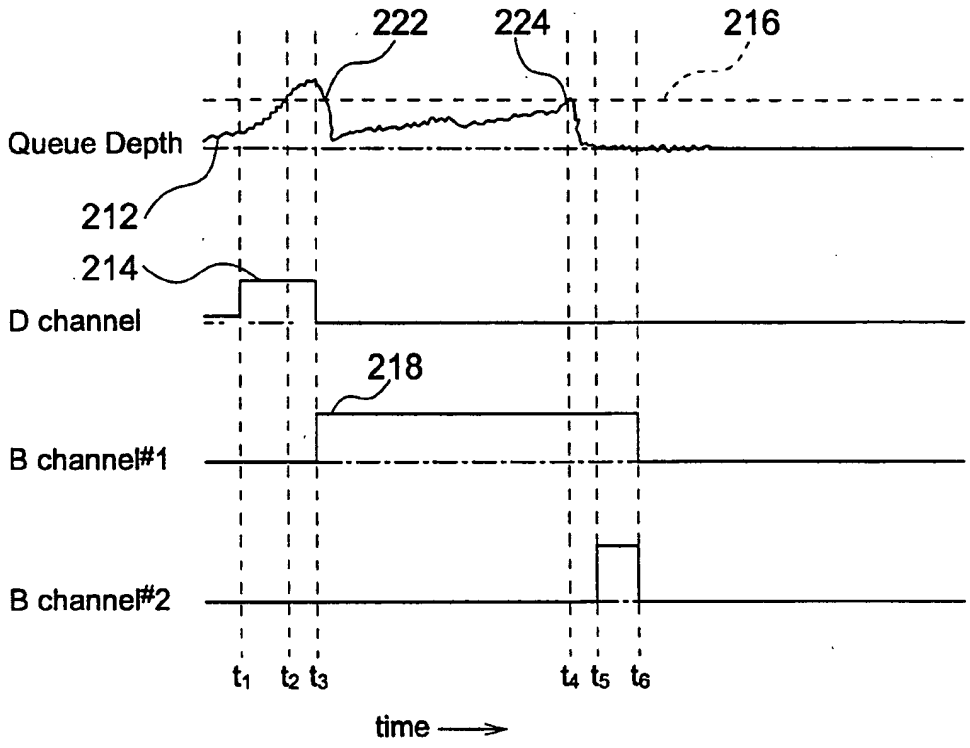

222
224
216
Queue Depth
212
214
D channel
218
B channel#1
B channel#2
t1 t2 t3 t4 t5 t6
time

Fig. 2

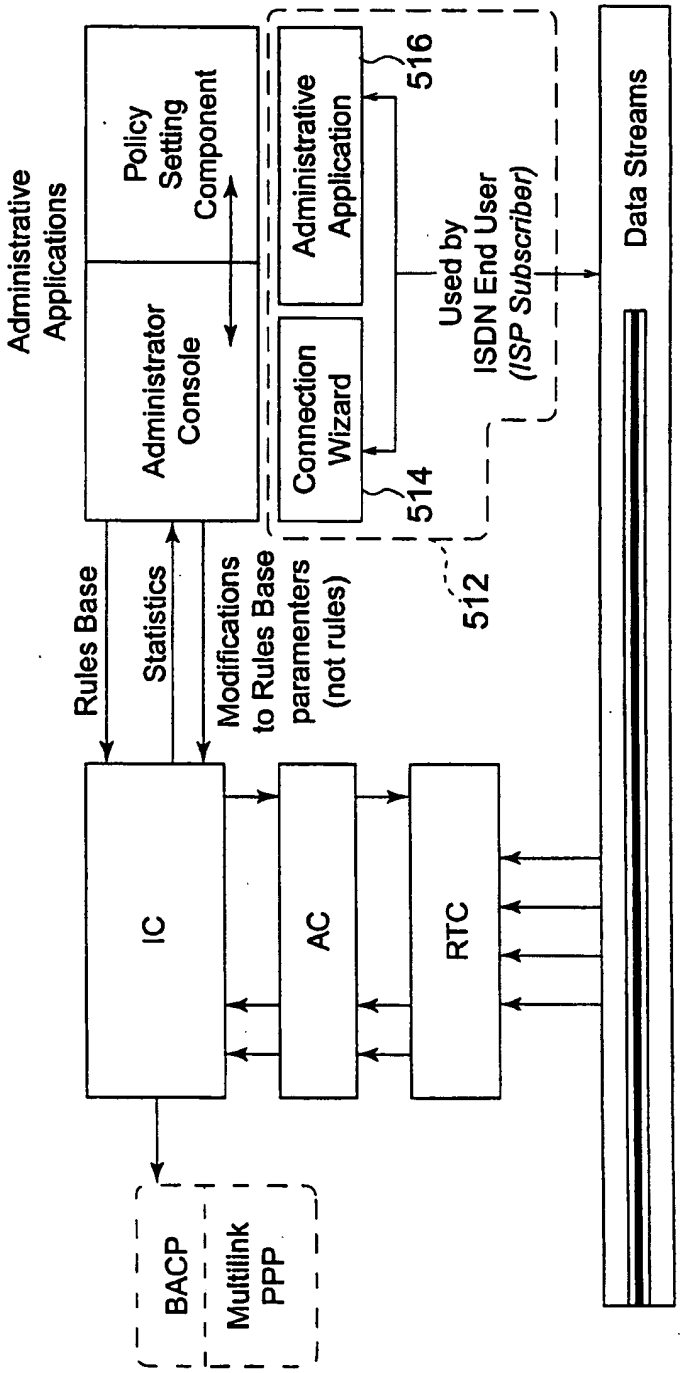

Administrative Applications
Policy Setting Component
Administrator Console
Administrative Application
516
Connection Wizard
514
Used by ISDN End User (ISP Subscriber)
512
Data Streams
Rules Base
Statistics
Modifications to Rules Base paramenters (not rules)
IC
AC
RTC
BACP
Multilink PPP

Fig. 5

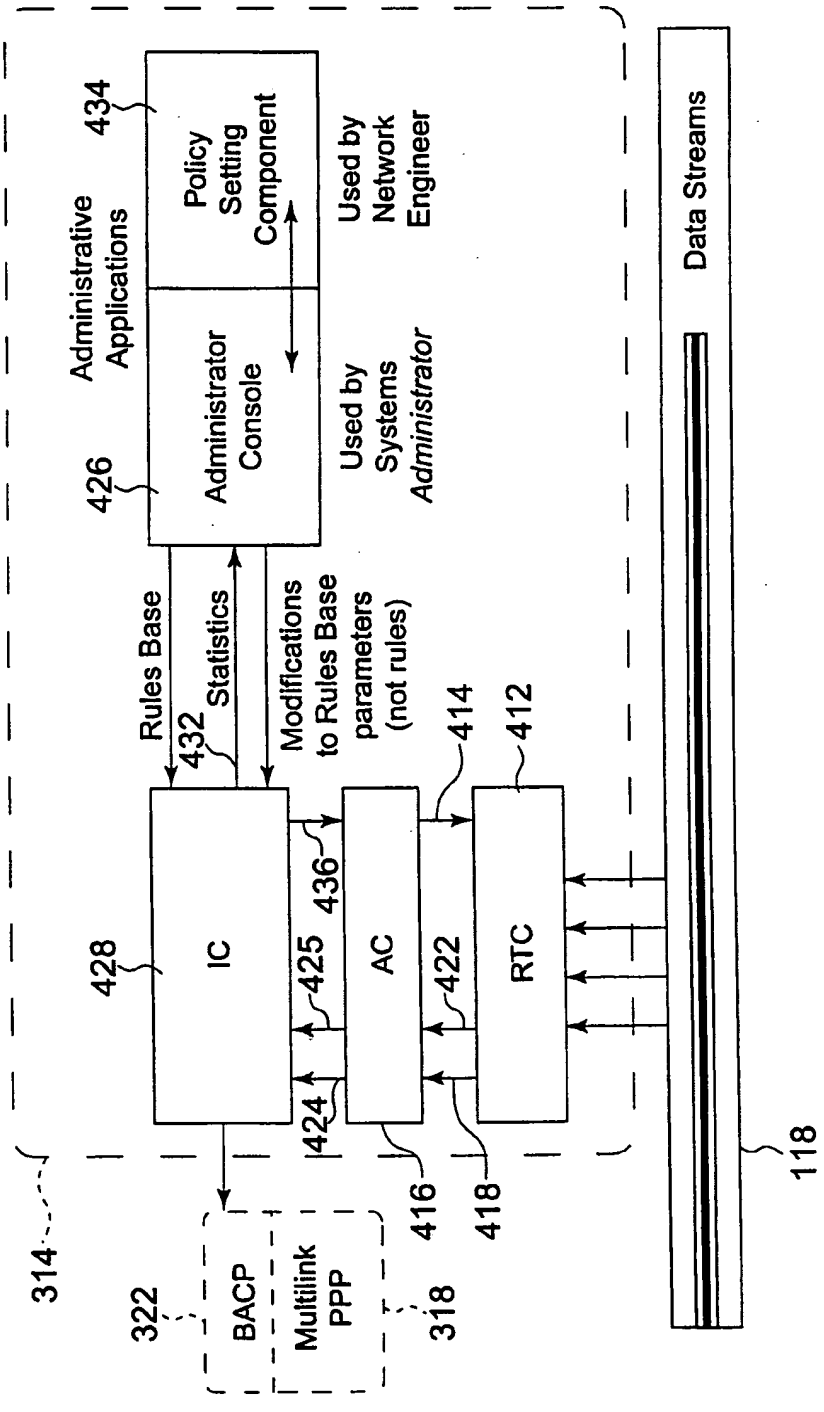

Administrative Applications
434
Policy Setting Component
Used by Network Engineer
426
Administrator Console
Used by Systems Administrator
Rules Base
Statistics
432
Modifications to Rules Base parameters (not rules)
414
412
428
IC
425
AC
436
422
RTC
424
Data Streams
118
314
322
BACP
Multilink PPP
318
416
418

Fig. 4

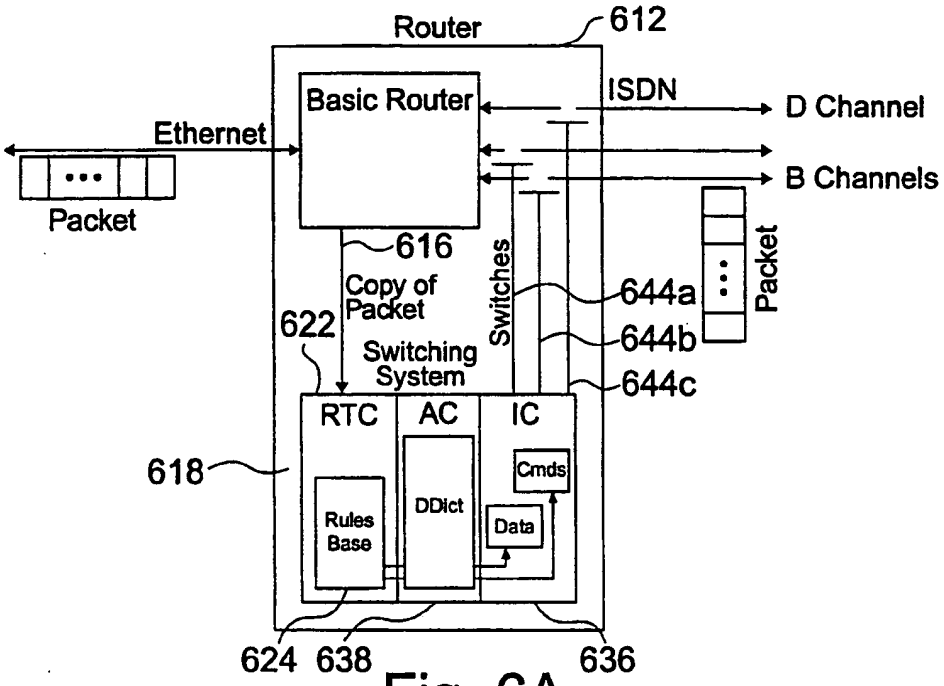

Router
612
Basic Router
ISDN
D Channel
Ethernet
B Channels
Packet
616
Copy of Packet
622
Switching System
Switches
644a
644b
644c
Packet
RTC
AC
IC
618
Rules Base
DDict
Cmds
Data
624
638
636

Fig. 6A

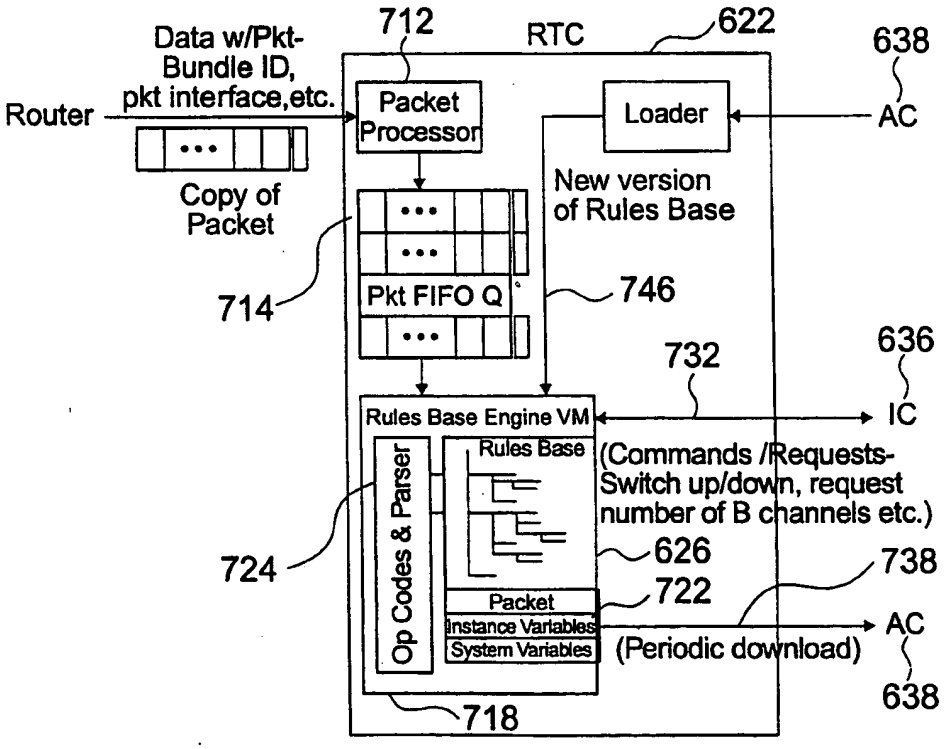

Data w/Pkt-Bundle ID, pkt interface,etc.
712
RTC
622
638
Router
Packet Processor
Loader
AC
Copy of Packet
New version of Rules Base
714
Pkt FIFO Q
746
732
636
Rules Base Engine VM
IC
Rules Base
(Commands /Requests-Switch up/down, request number of B channels etc.)
Op Codes & Parser
724
626
738
Packet
722
Instance Variables
System Variables
(Periodic download)
AC
638
718

Fig. 7A

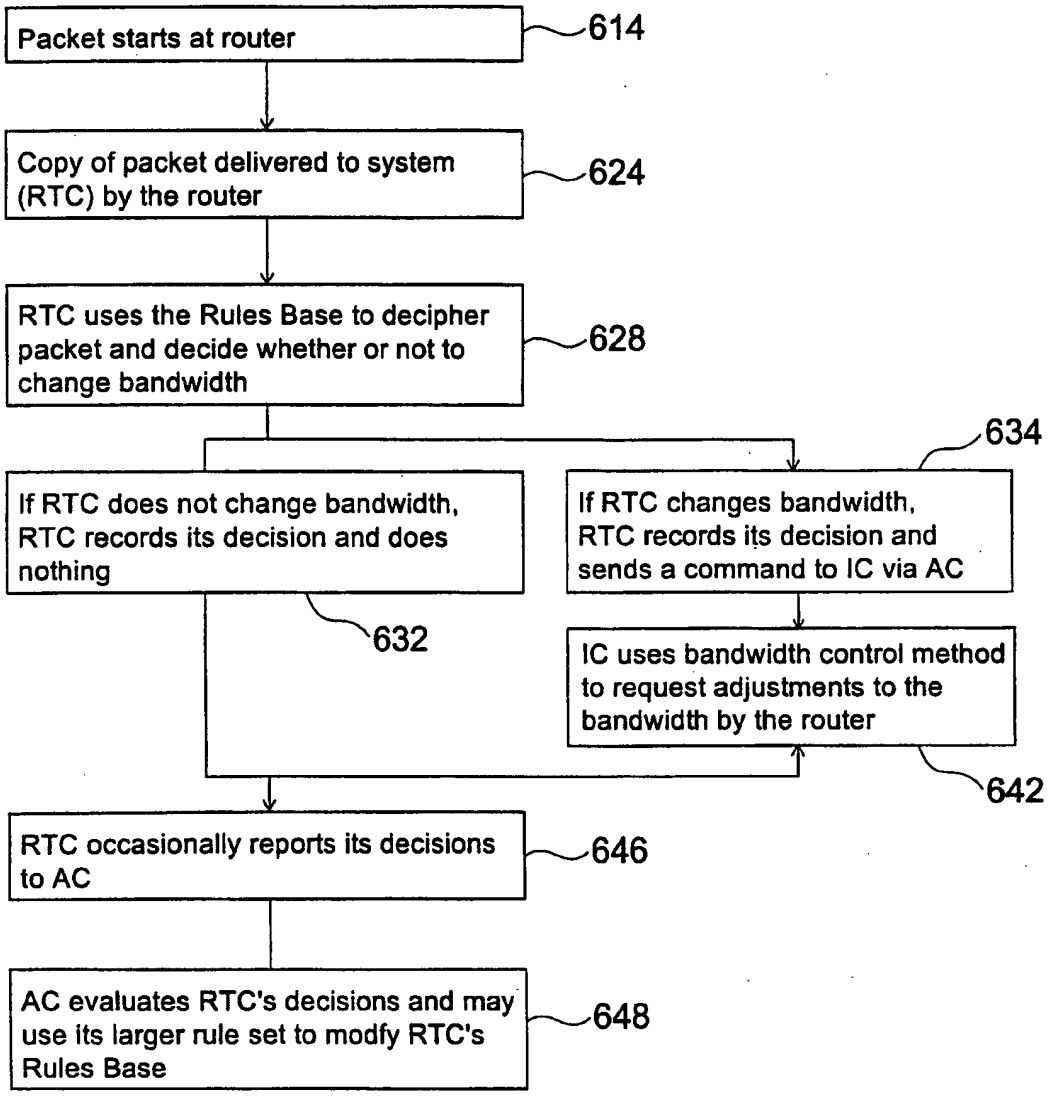

Packet starts at router
614
Copy of packet delivered to system (RTC) by the router
624
RTC uses the Rules Base to decipher packet and decide whether or not to change bandwidth
628
634
If RTC does not change bandwidth, RTC records its decision and does nothing
632
If RTC changes bandwidth, RTC records its decision and sends a command to IC via AC
IC uses bandwidth control method to request adjustments to the bandwidth by the router
642
RTC occasionally reports its decisions to AC
646
AC evaluates RTC's decisions and may use its larger rule set to modfy RTC's Rules Base
648

Fig. 6B

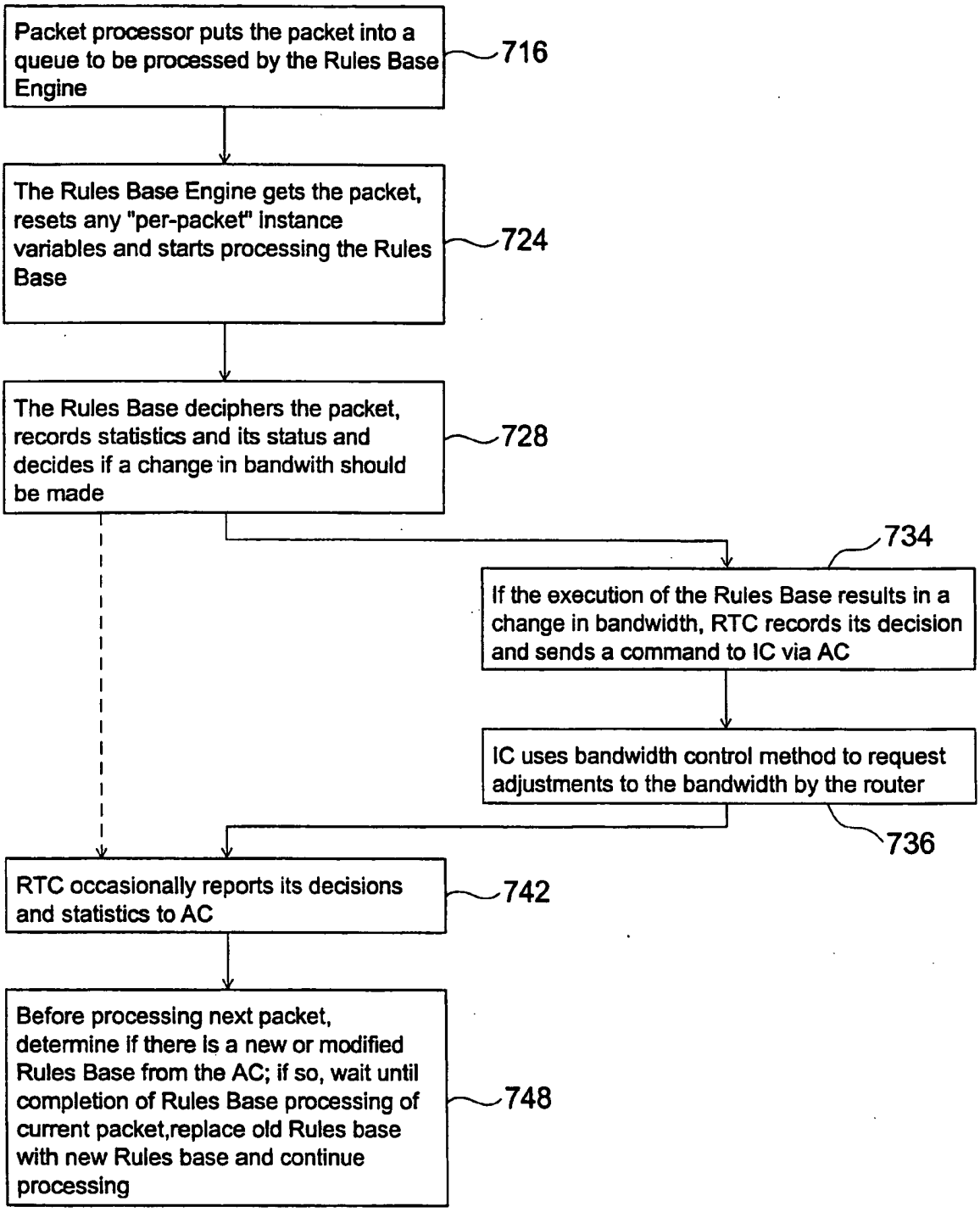

Packet processor puts the packet into a queue to be processed by the Rules Base Engine
716
The Rules Base Engine gets the packet, resets any "per-packet" instance variables and starts processing the Rules Base
724
The Rules Base deciphers the packet, records statistics and its status and decides if a change in bandwith should be made
728
734
If the execution of the Rules Base results in a change in bandwidth, RTC records its decision and sends a command to IC via AC
IC uses bandwidth control method to request adjustments to the bandwidth by the router
736
RTC occasionally reports its decisions and statistics to AC
742
Before processing next packet, determine if there is a new or modified Rules Base from the AC; if so, wait until completion of Rules Base processing of current packet,replace old Rules base with new Rules base and continue processing
748

Fig. 7B

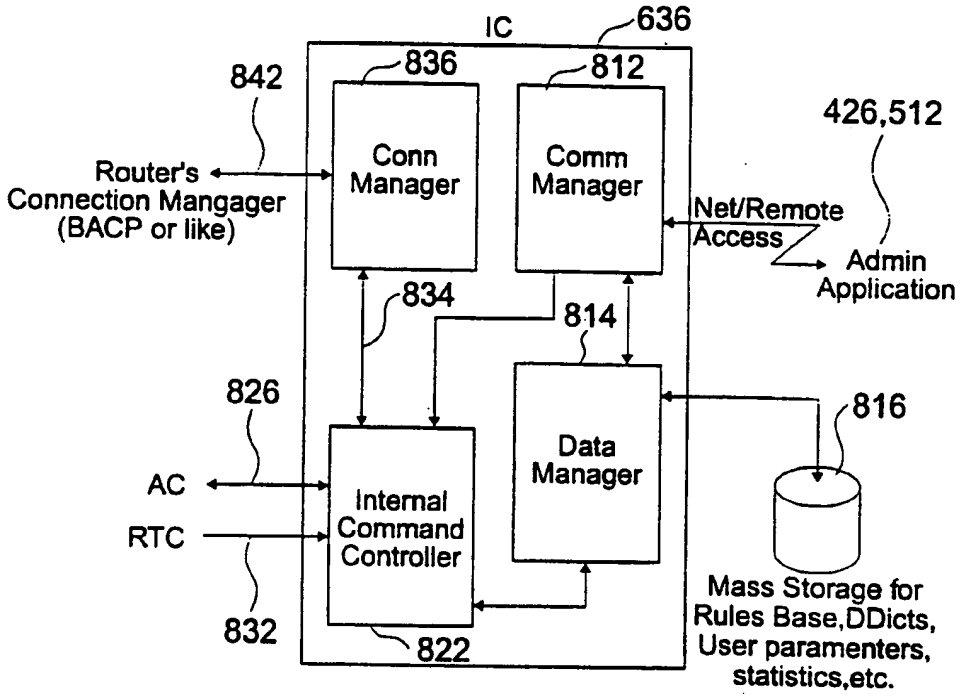

IC
636
836
812
842
426,512
Router's
Connection Mangager
(BACP or like)
Conn
Manager
Comm
Manager
Net/Remote
Access
Admin
Application
834
814
826
816
AC
RTC
Internal
Command
Controller
Data
Manager
832
822
Mass Storage for
Rules Base,DDicts,
User paramenters,
statistics,etc.

Fig.8A

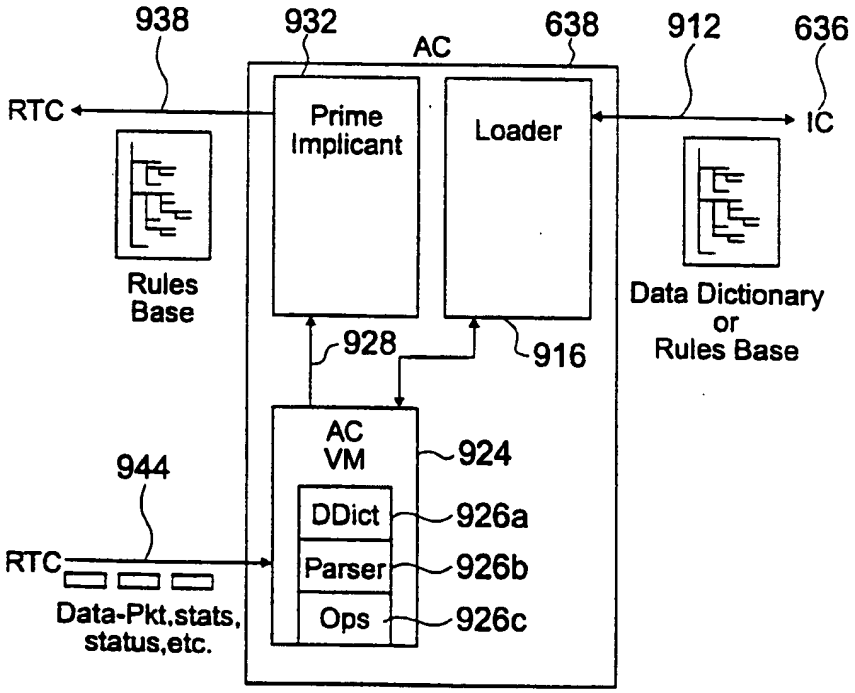

938
932
AC
638
912
636
RTC
Prime
Implicant
Loader
IC
Rules
Base
Data Dictionary
or
Rules Base
928
916
AC
VM
924
944
DDict
926a
RTC
Parser
926b
Ops
926c
Data-Pkt,stats,
status,etc.

Fig. 9A

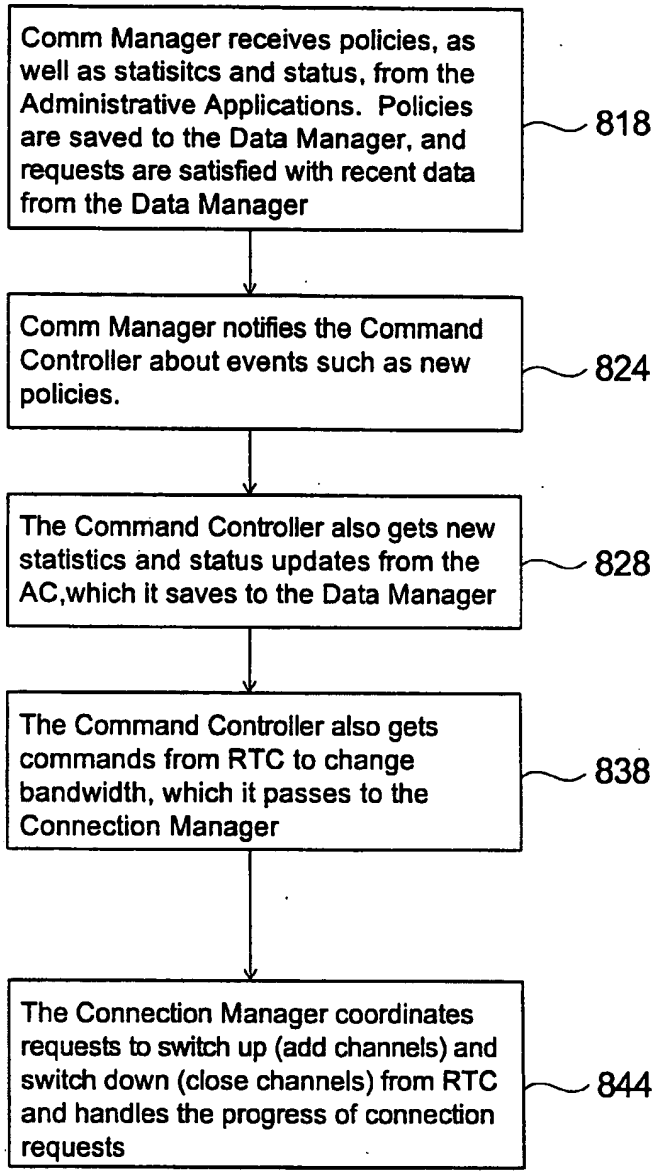

Comm Manager receives policies, as well as statisitcs and status, from the Administrative Applications. Policies are saved to the Data Manager, and requests are satisfied with recent data from the Data Manager
818
Comm Manager notifies the Command Controller about events such as new policies.
824
The Command Controller also gets new statistics and status updates from the AC,which it saves to the Data Manager
828
The Command Controller also gets commands from RTC to change bandwidth, which it passes to the Connection Manager
838
The Connection Manager coordinates requests to switch up (add channels) and switch down (close channels) from RTC and handles the progress of connection requests
844

Fig. 8B

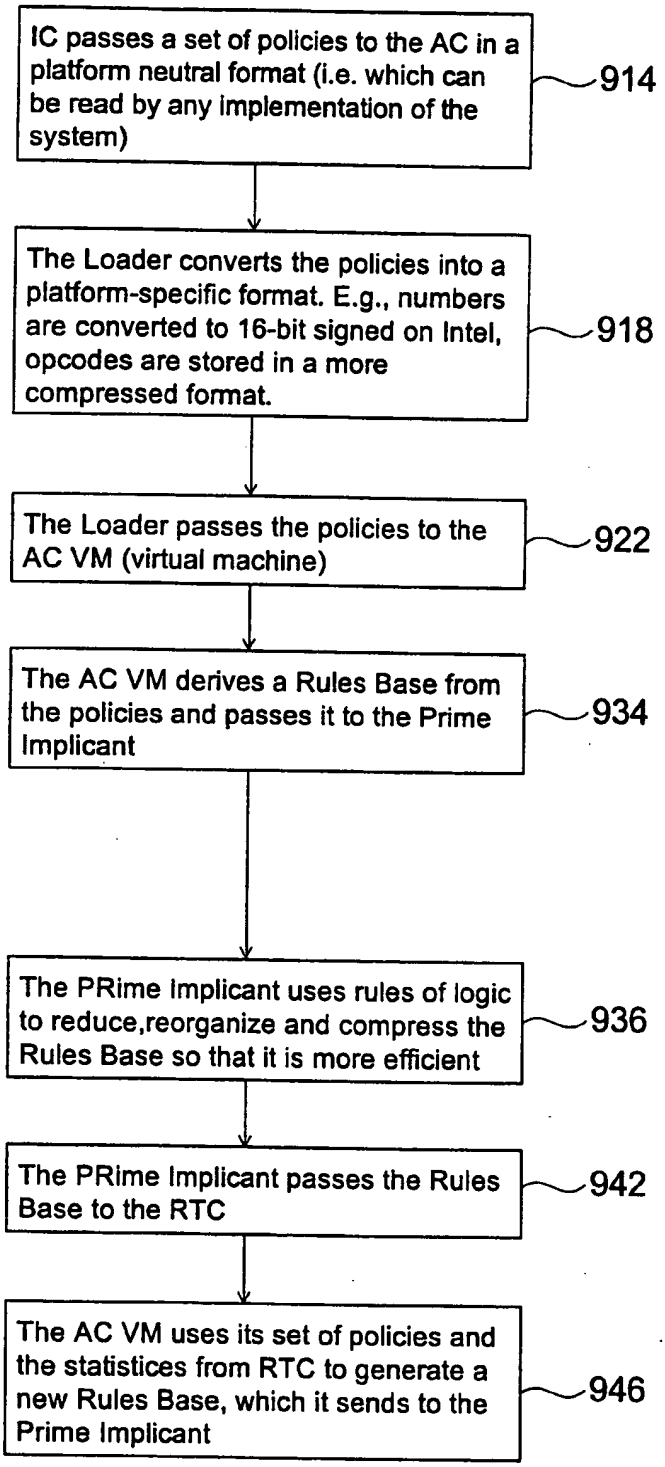

IC passes a set of policies to the AC in a platform neutral format (i.e. which can be read by any implementation of the system)
914
The Loader converts the policies into a platform-specific format. E.g., numbers are converted to 16-bit signed on Intel, opcodes are stored in a more compressed format.
918
The Loader passes the policies to the AC VM (virtual machine)
922
The AC VM derives a Rules Base from the policies and passes it to the Prime Implicant
934
The PRime Implicant uses rules of logic to reduce,reorganize and compress the Rules Base so that it is more efficient
936
The PRime Implicant passes the Rules Base to the RTC
942
The AC VM uses its set of policies and the statistices from RTC to generate a new Rules Base, which it sends to the Prime Implicant
946

Fig. 9B

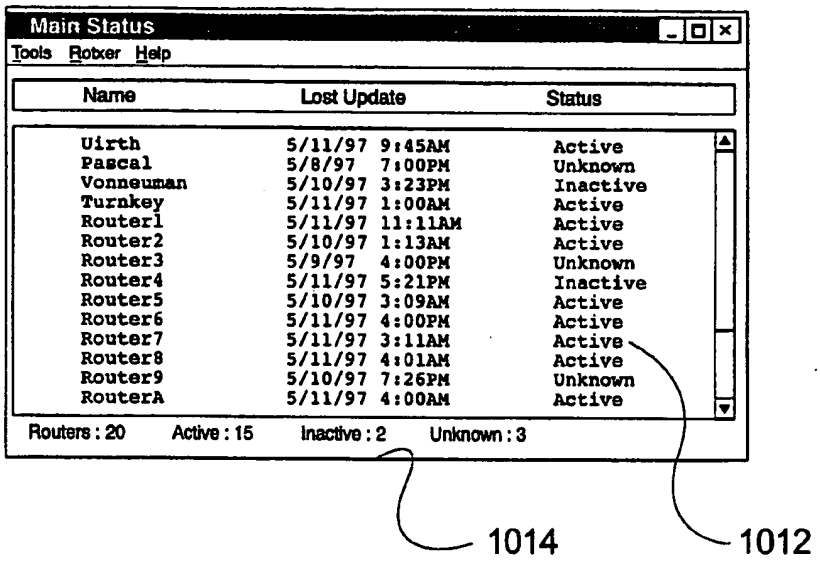

Main Status
Tools Rotxer Help
Name Lost Update Status
Uirth 5/11/97 9:45AM Active
Pascal 5/8/97 7:00PM Unknown
Vonneuman 5/10/97 3:23PM Inactive
Turnkey 5/11/97 1:00AM Active
Router1 5/11/97 11:11AM Active
Router2 5/10/97 1:13AM Active
Router3 5/9/97 4:00PM Unknown
Router4 5/11/97 5:21PM Inactive
Router5 5/10/97 3:09AM Active
Router6 5/11/97 4:00PM Active
Router7 5/11/97 3:11AM Active
Router8 5/11/97 4:01AM Active
Router9 5/10/97 7:26PM Unknown
RouterA 5/11/97 4:00AM Active
Routers : 20 Active : 15 Inactive : 2 Unknown : 3
1014
1012

FIG. 10

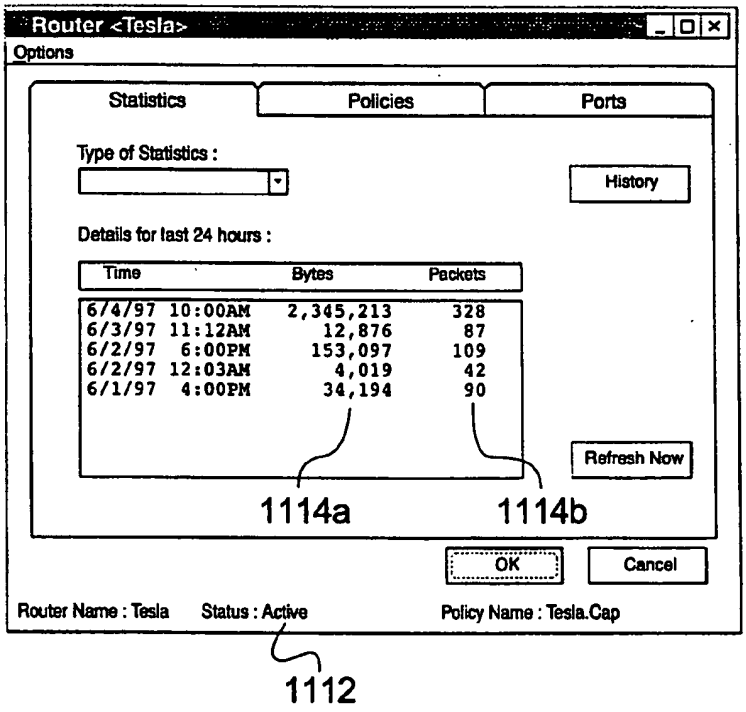

Router <Tesla>
Options
Statistics
Policies
Ports
Type of Statistics :
History
Details for last 24 hours :
Time Bytes Packets
6/4/97 10:00AM 2,345,213 328
6/3/97 11:12AM 12,876 87
6/2/97 6:00PM 153,097 109
6/2/97 12:03AM 4,019 42
6/1/97 4:00PM 34,194 90
Refresh Now
1114a
1114b
OK
Cancel
Router Name : Tesla Status : Active Policy Name : Tesla.Cap
1112

FIG. 11

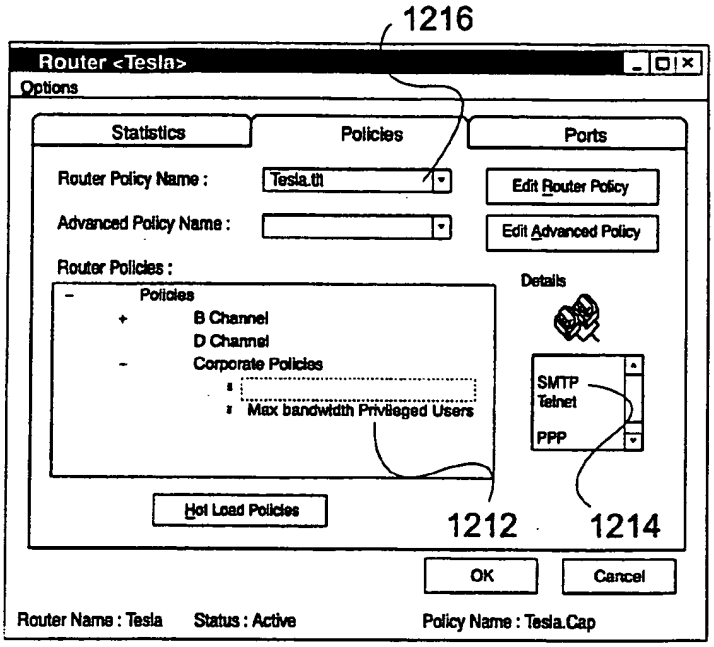

1216
Router <Tesla>
Options
Statistics
Policies
Ports
Router Policy Name :
Tesla.tll
Edit Router Policy
Advanced Policy Name :
Edit Advanced Policy
Router Policies :
Policies
B Channel
D Channel
Corporate Policies
Max bandwidth Privileged Users
Details
SMTP
Telnet
PPP
Hot Load Policies
1212
1214
OK
Cancel
Router Name : Tesla
Status : Active
Policy Name : Tesla.Cap

FIG. 12

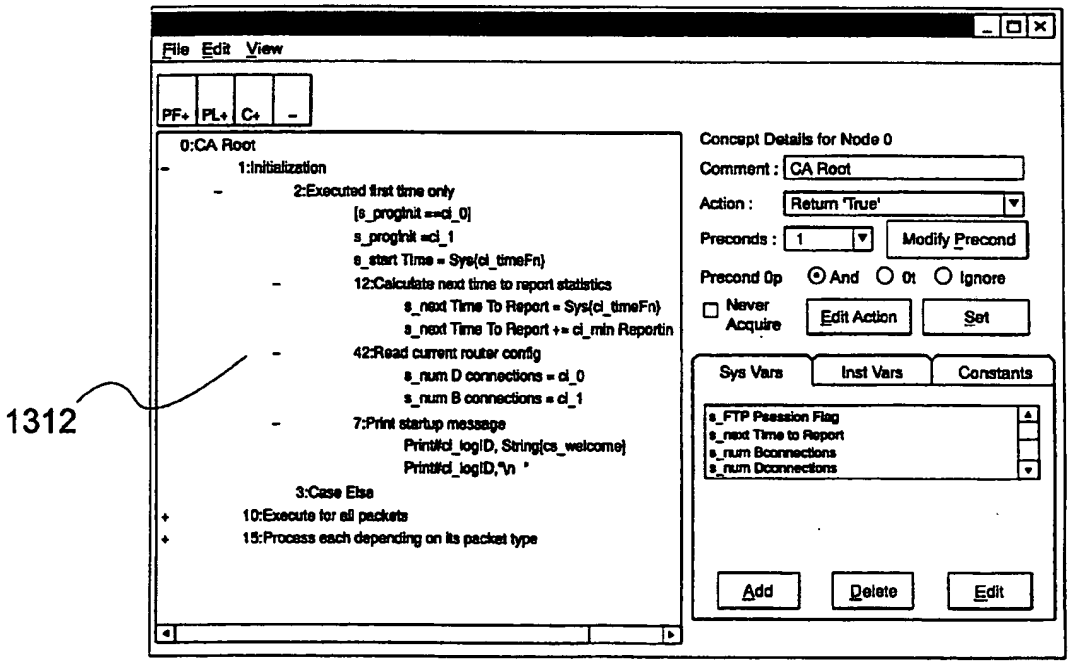

File Edit View
PF+
PL+
C+
0:CA Root
1:Initialization
2:Executed first time only
[s_proginit ==ci_0]
s_proginit =ci_1
s_start Time = Sys(ci_timeFn)
12:Calculate next time to report statistics
s_next Time To Report = Sys(ci_timeFn)
s_next Time To Report += ci_min Reportin
42:Read current router config
s_num D connections = ci_0
s_num B connections = ci_1
7:Print startup message
Print#ci_logID, String(cs_welcome)
Print#ci_logID,"\n "
3:Case Else
10:Execute for all packets
15:Process each depending on its packet type
1312
Concept Details for Node 0
Comment :
CA Root
Action :
Return 'True'
Preconds :
1
Modify Precond
Precond Op
And
Or
Ignore
Never Acquire
Edit Action
Set
Sys Vars
Inst Vars
Constants
s_FTP Psession Flag
s_next Time to Report
s_num Bconnections
s_num Dconnections
Add
Delete
Edit

FIG. 13

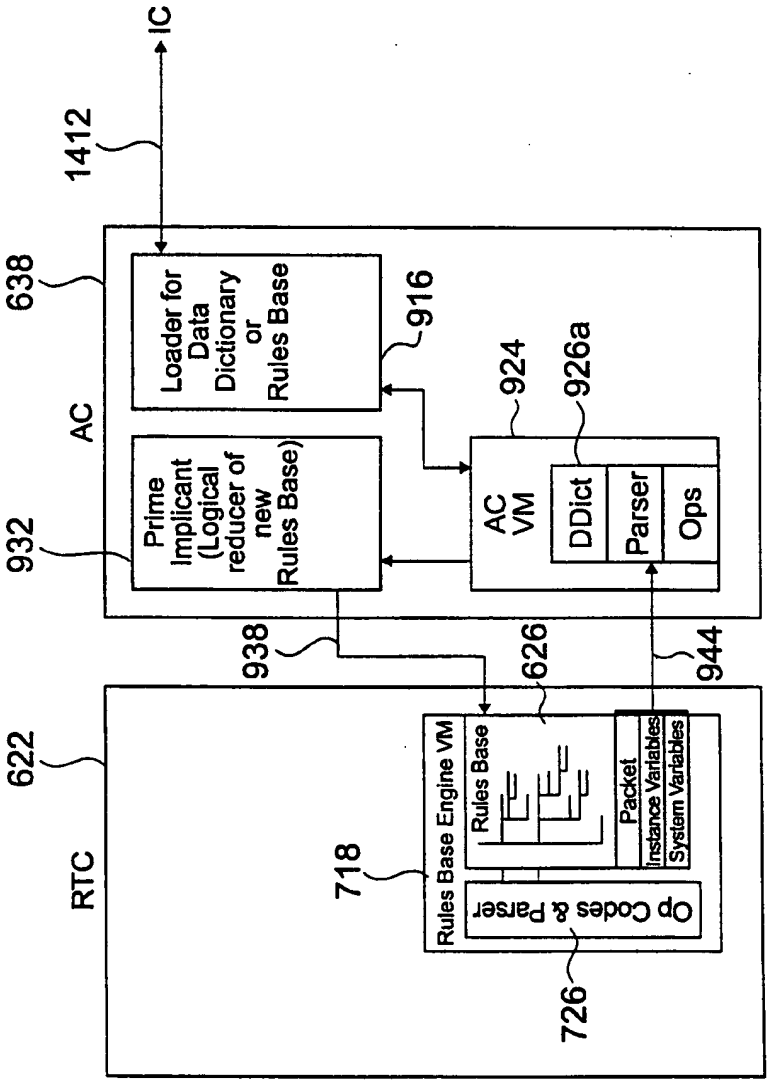

IC
1412
638
AC
Loader for Data Dictionary or Rules Base
916
924
926a
932
Prime Implicant (Logical reducer of new Rules Base)
AC VM
DDict
Parser
Ops
938
626
944
622
RTC
718
Rules Base Engine VM
Rules Base
Packet
Instance Variables
System Variables
Op Codes & Parser
726

Fig. 14A

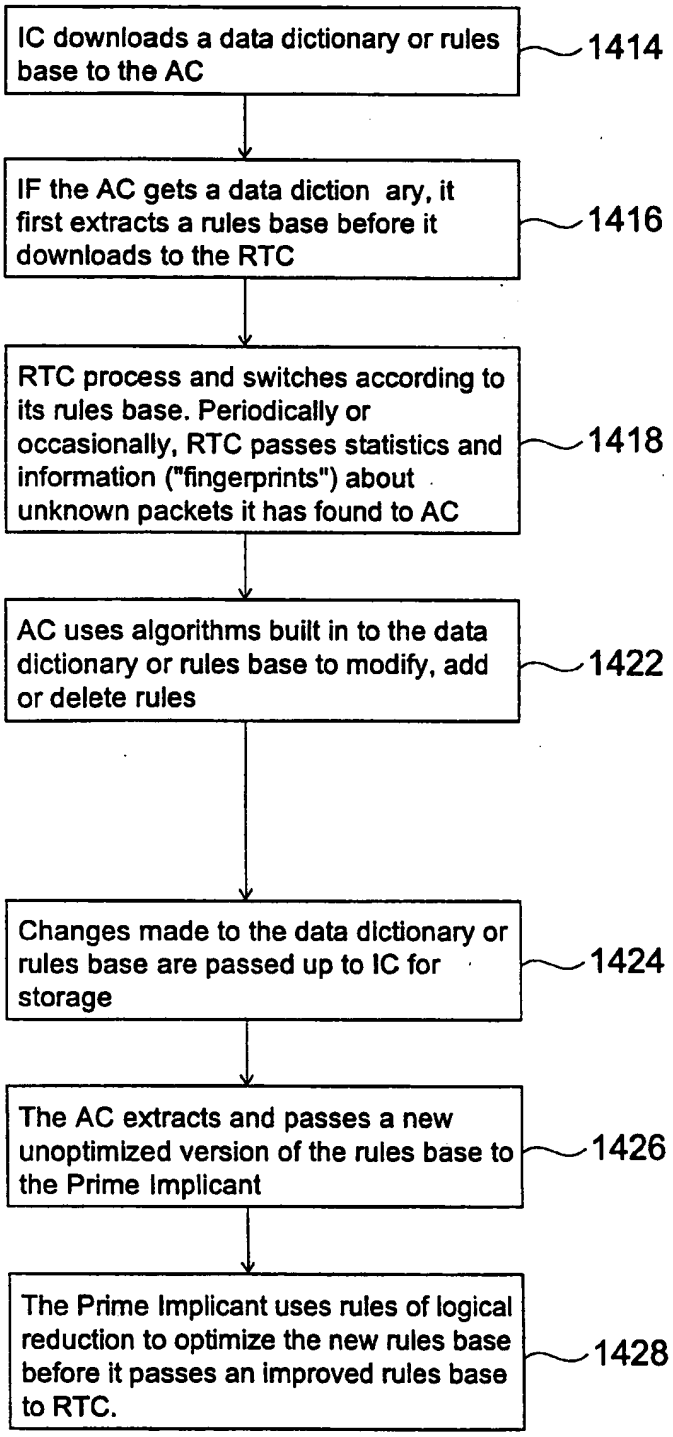

IC downloads a data dictionary or rules base to the AC
1414
IF the AC gets a data diction ary, it first extracts a rules base before it downloads to the RTC
1416
RTC process and switches according to its rules base. Periodically or occasionally, RTC passes statistics and information ("fingerprints") about unknown packets it has found to AC
1418
AC uses algorithms built in to the data dictionary or rules base to modify, add or delete rules
1422
Changes made to the data dictionary or rules base are passed up to IC for storage
1424
The AC extracts and passes a new unoptimized version of the rules base to the Prime Implicant
1426
The Prime Implicant uses rules of logical reduction to optimize the new rules base before it passes an improved rules base to RTC.
1428

Fig 14B

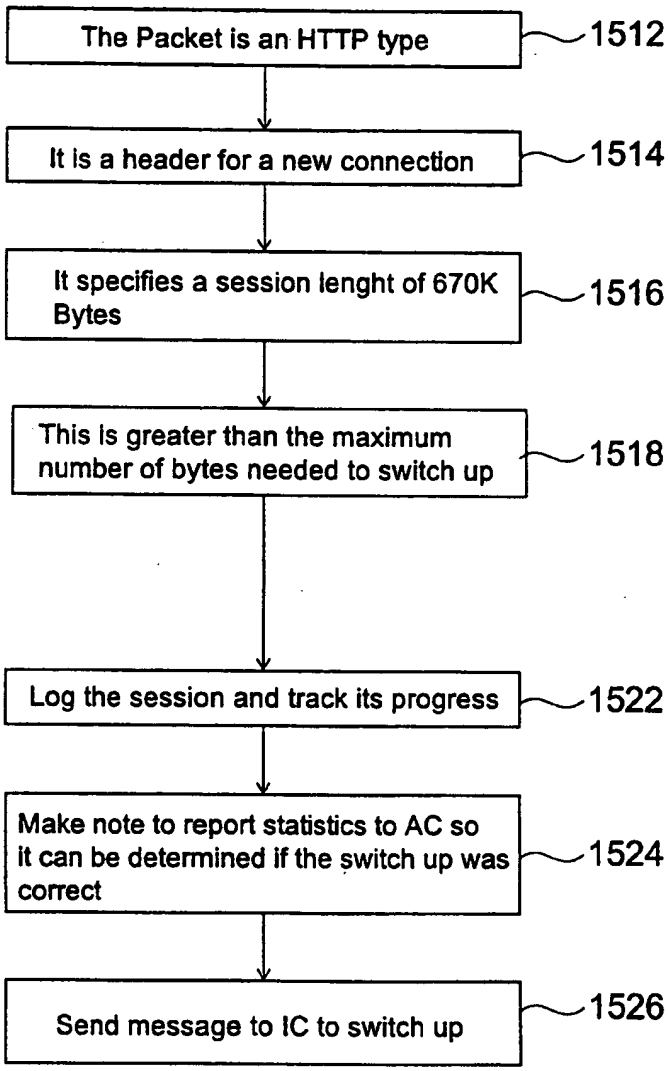

The Packet is an HTTP type
1512
It is a header for a new connection
1514
It specifies a session lenght of 670K Bytes
1516
This is greater than the maximum number of bytes needed to switch up
1518
Log the session and track its progress
1522
Make note to report statistics to AC so it can be determined if the switch up was correct
1524
Send message to IC to switch up
1526

Fig. 15

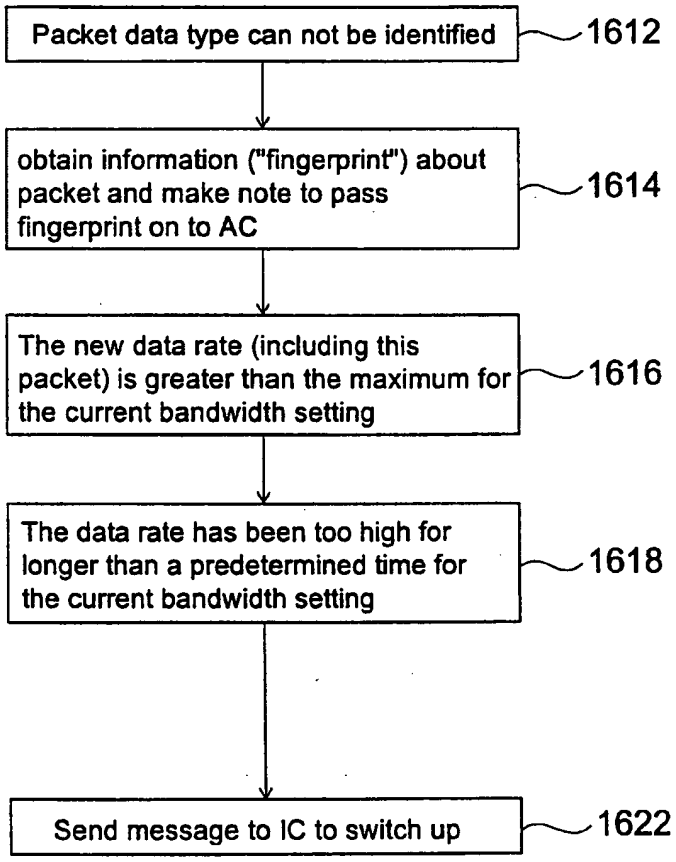

Packet data type can not be identified
1612
obtain information ("fingerprint") about packet and make note to pass fingerprint on to AC
1614
The new data rate (including this packet) is greater than the maximum for the current bandwidth setting
1616
The data rate has been too high for longer than a predetermined time for the current bandwidth setting
1618
Send message to IC to switch up
1622

Fig. 16

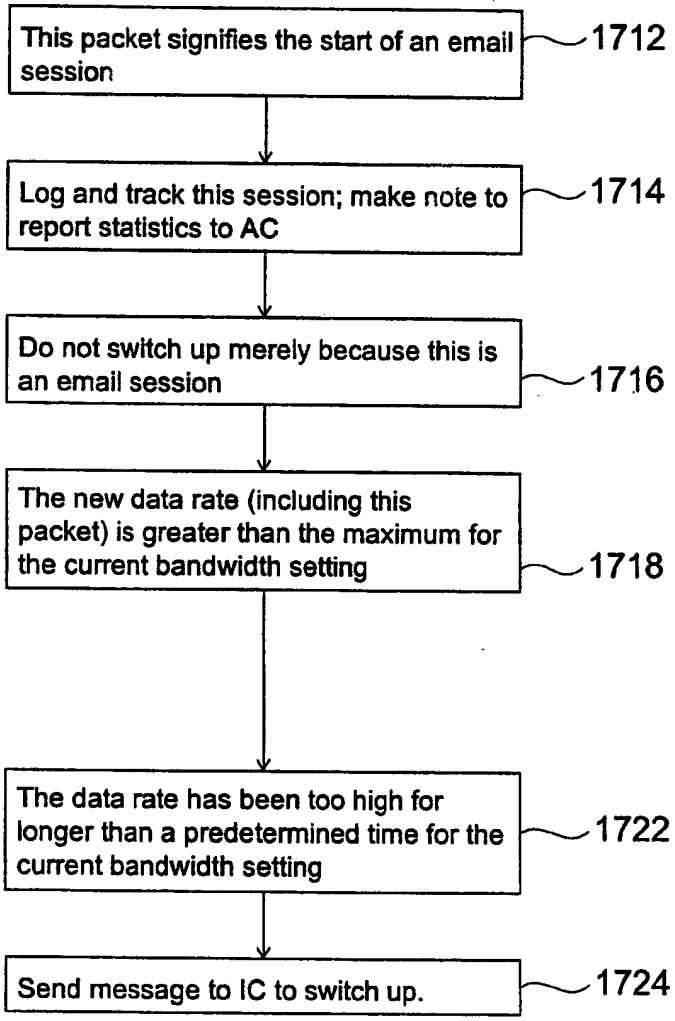

This packet signifies the start of an email session
1712
Log and track this session; make note to report statistics to AC
1714
Do not switch up merely because this is an email session
1716
The new data rate (including this packet) is greater than the maximum for the current bandwidth setting
1718
The data rate has been too high for longer than a predetermined time for the current bandwidth setting
1722
Send message to IC to switch up.
1724

Fig. 17

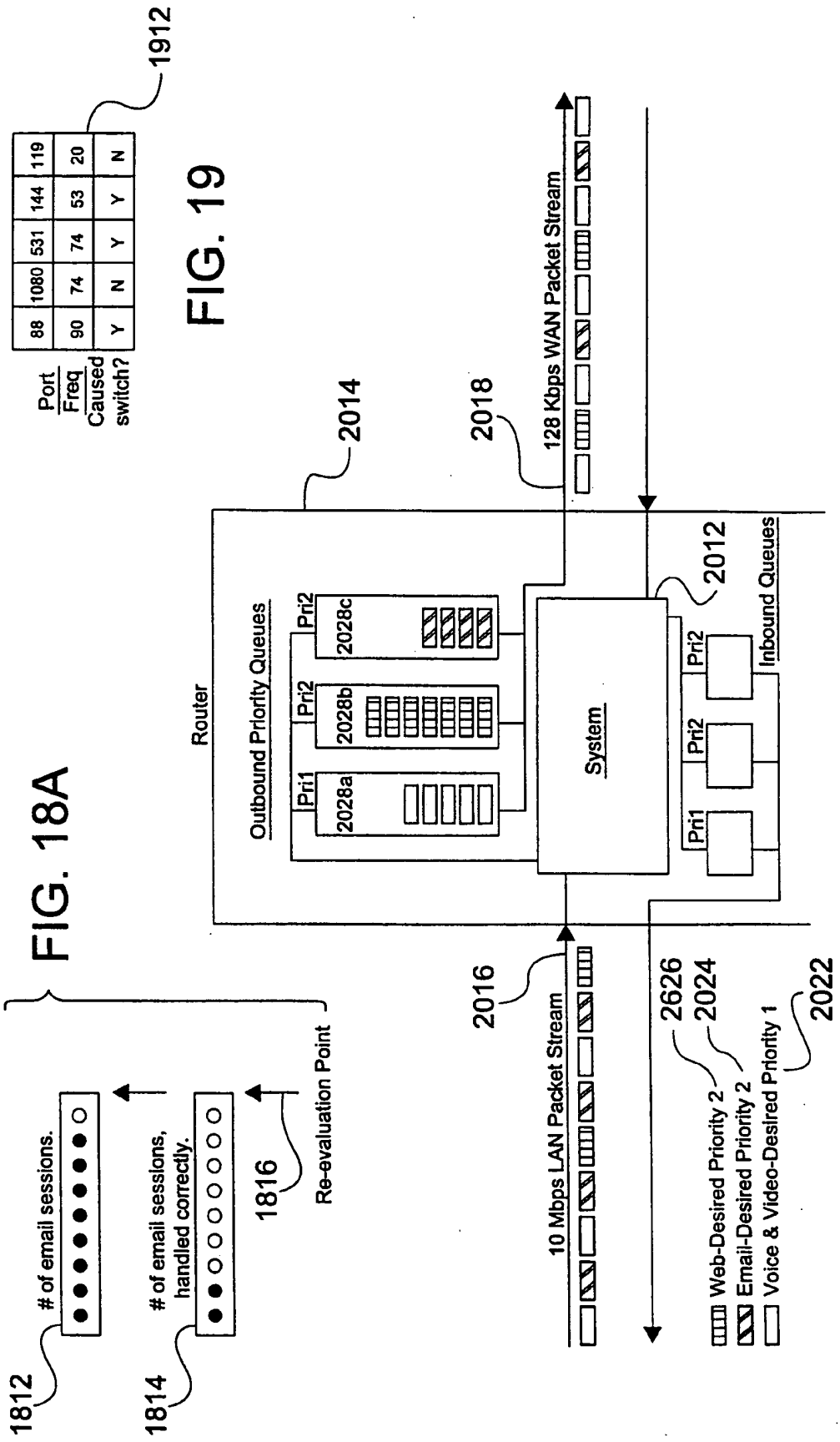


FIG. 18A

FIG. 19

FIG. 20

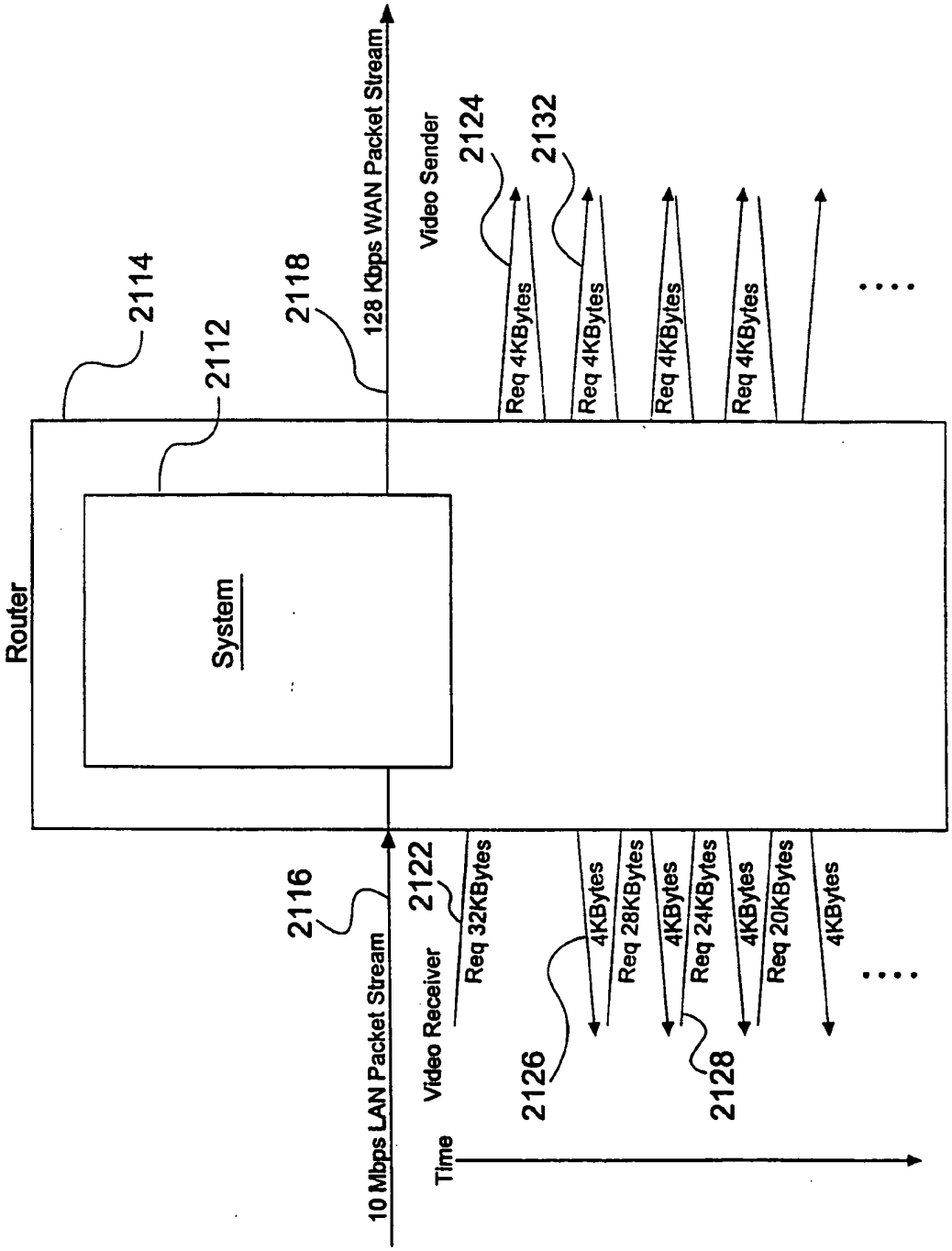

Router
System
2114
2112
2118
128 Kbps WAN Packet Stream
Video Sender
2124
2132
Req 4KBytes
Req 4KBytes
Req 4KBytes
Req 4KBytes
2116
2122
10 Mbps LAN Packet Stream
Video Receiver
Req 32KBytes
4KBytes
Req 28KBytes
4KBytes
Req 24KBytes
4KBytes
Req 20KBytes
4KBytes
2126
2128
Time

FIG. 21

FIG. 22

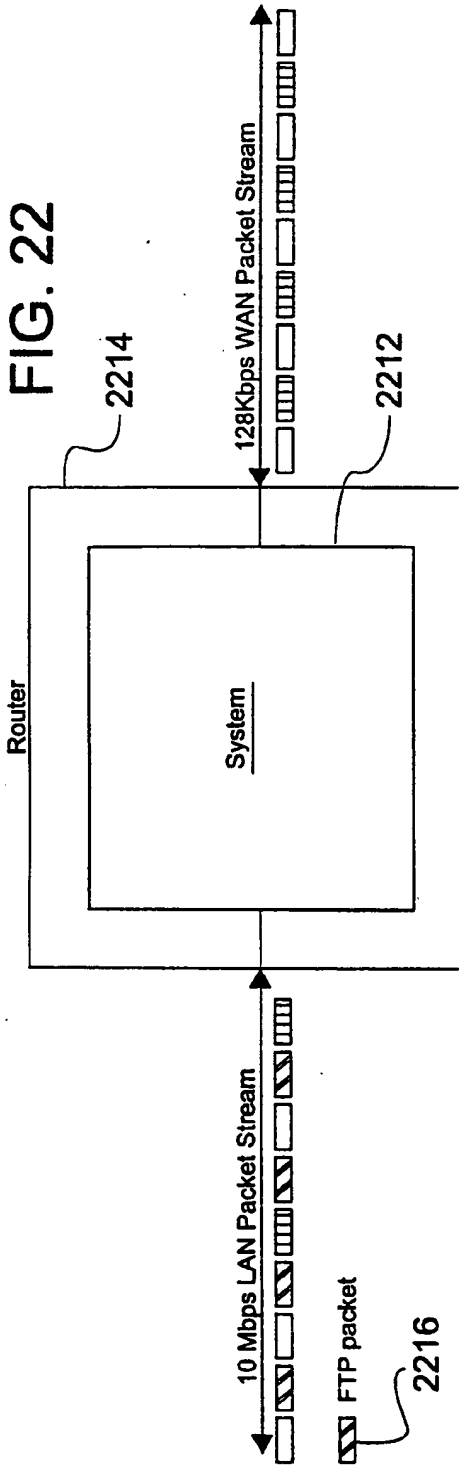
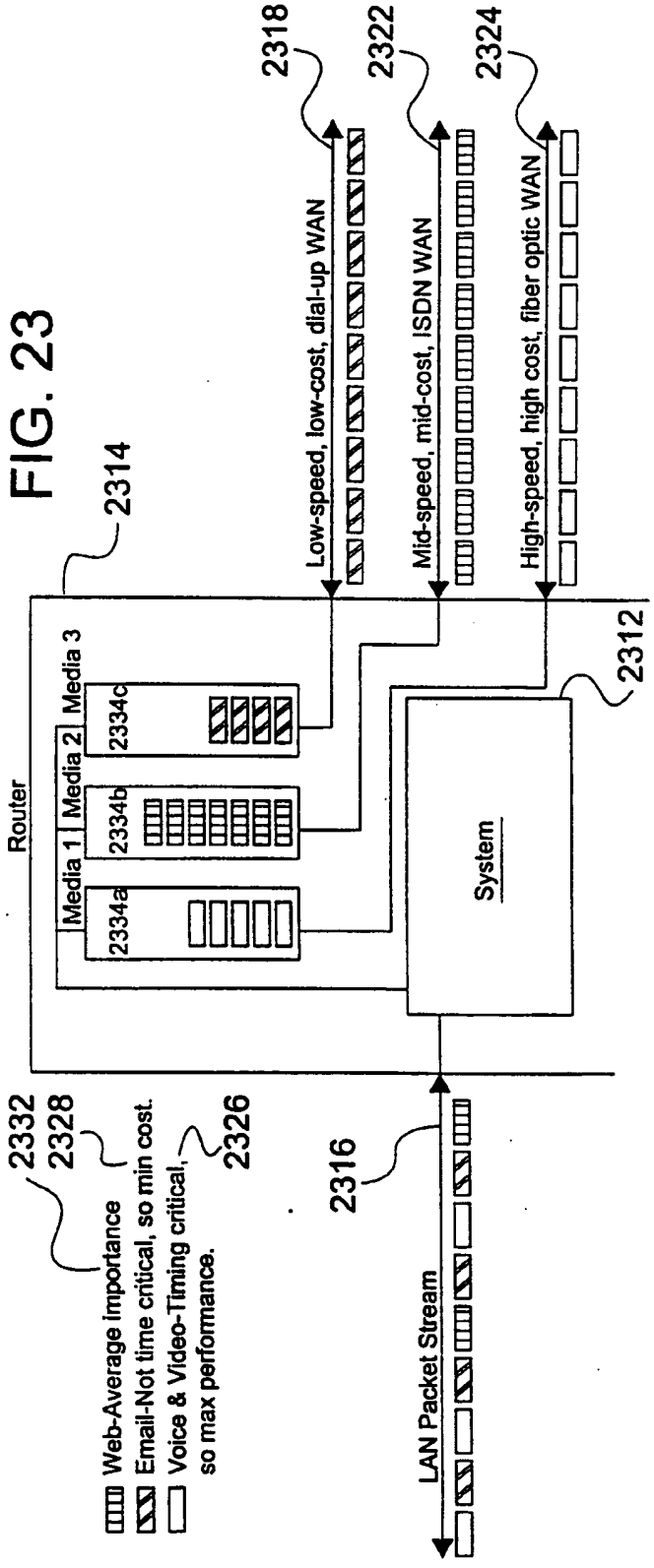

2214
128Kbps WAN Packet Stream
2212
Router
System
10 Mbps LAN Packet Stream
FTP packet
2216

FIG. 23


2318
2322
2324
2314
Low-speed, low-cost, dial-up WAN
Mid-speed, mid-cost, ISDN WAN
High-speed, high cost, fiber optic WAN
Media 1
Media 2
Media 3
2334a
2334b
2334c
Router
2312
System
2332
2328
2326
2316
Web-Average importance
Email-Not time critical, so min cost.
Voice & Video-Timing critical, so max performance.
LAN Packet Stream

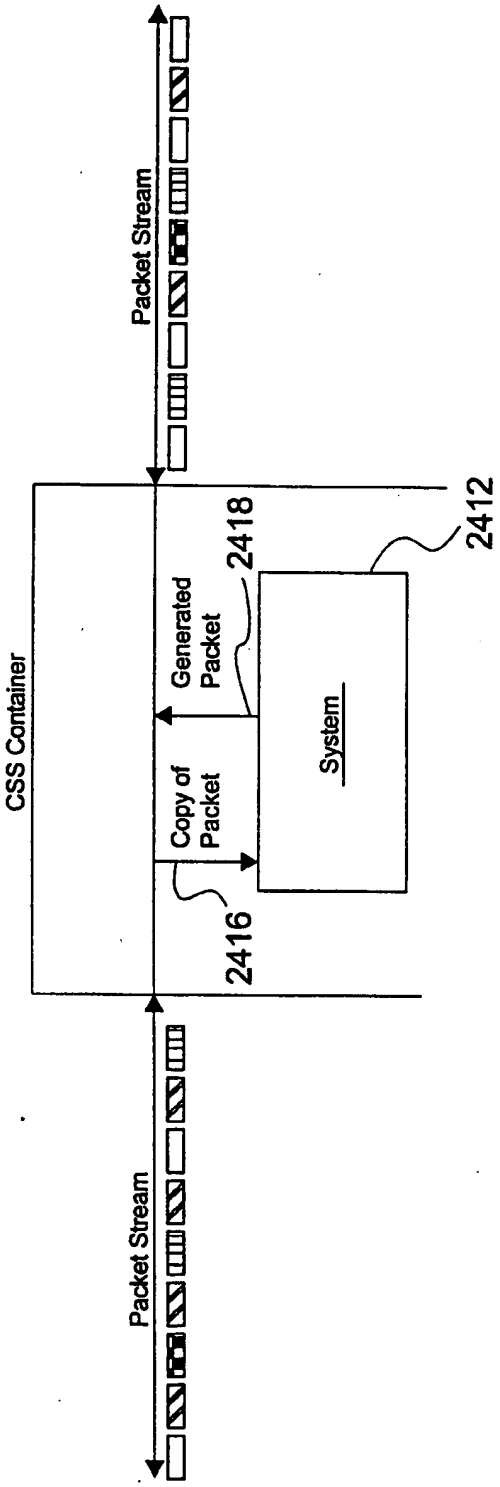

Packet Stream
CSS Container
Generated Packet
2418
2412
System
Copy of Packet
2416
Packet Stream

FIG. 24